

IEEE Std 3004.5™-2014

Recommended Practice for the
Application of Low-Voltage Circuit
Breakers in Industrial and
Commercial Power Systems



IEEE Recommended Practice for the Application of Low-Voltage Circuit Breakers in Industrial and Commercial Power Systems

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Abstract: Information for selecting the proper circuit breaker for a particular application is provided. Application engineers are aided in specifying the type of circuit breaker, ratings, trip functions, and accessories. Circuit breakers for special applications, e.g., instantaneous only and switches are discussed. In addition, information for applying circuit breakers at different locations in the power system and for protecting specific components is provided.

Keywords: circuit breakers, circuit breaker evaluation, IEEE 3004.5™, insulated case, insulated-case circuit breakers, low-voltage circuit breaker, low-voltage power circuit breaker, low-voltage protection, low-voltage protection device, miniature circuit breaker, molded case, molded-case circuit breaker, overcurrent protection, power circuit breaker, rating

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This recommended practice was developed by the Technical Books Coordinating Committee of the Industrial and Commercial Power Systems Department of the Industry Applications Society as part of a project to repackage the popular IEEE Color Books®. The goal of this project is to speed up the revision process, eliminate duplicate material, and facilitate use of modern publishing and distribution technologies.

When this project is completed, the technical material in the thirteen IEEE Color Books will be included in a series of new standards—the most significant of which will be a new standard, IEEE Std 3000™, IEEE Recommended Practice for the Engineering of Industrial and Commercial Power Systems. The new standard will cover the fundamentals of planning, design, analysis, construction, installation, startup, operation, and maintenance of electrical systems in industrial and commercial facilities. Approximately 60 additional dot standards, organized into the following categories, will provide in-depth treatment of many of the topics introduced by IEEE Std 3000:

- Power Systems Design (3001 series)
- Power Systems Analysis (3002 series)
- Power Systems Grounding and Bonding (3003 series)
- Protection and Coordination (3004 series)
- Emergency, Standby Power, and Energy Management Systems (3005 series)
- Power Systems Reliability (3006 series)
- Power Systems Maintenance, Operations, and Safety (3007 series)

In many cases, the material in a dot standard comes from a particular chapter of a particular IEEE Color Book. In other cases, material from several IEEE Color Books has been combined into a new dot standard.

IEEE Std 3004.5™

This recommended practice provides an engineer a comprehensive reference source to aid in deciding what type of low-voltage circuit breaker to use for a particular application, and how to apply the circuit breaker. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems based on North American product standards. Similar related devices are covered by other standards, including International Electrotechnical Commission (IEC) standards, predominant in Europe and other regions. This recommended practice includes a comparison between the standards of low-voltage power circuit breakers and molded-case circuit breakers so that an engineer can make better, more informed choices. Pertinent tables have been extracted from other standards to provide the basis for the selection and application guidelines. In addition, specific application examples are provided.

The material in this recommended practice was originally published in the first edition of IEEE Std 1015™ (*IEEE Blue Book*™) in 1997 and is an update of the material in Chapters 1 through 4, and Chapter 6 of the 2006 edition. It also encompasses the material in Chapter 7 of IEEE Std 242™-2001 (*IEEE Buff Book*™).

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1. Overview

1.1 Scope

This recommended practice covers the selection and application of low-voltage circuit breakers used in industrial and commercial power systems.

1.2 Low-voltage circuit breaker classifications

For low-voltage circuit protection in North America, circuit breaker designs are based on the requirements of three standards organizations: the American National Standards Institute (ANSI), Underwriters Laboratories (UL), and the National Electrical Manufacturers Association (NEMA).

The two classifications of circuit breakers these organizations define are as follows:

- a) Molded-case circuit breaker (MCCB) class
- b) Low-voltage power circuit breaker (LVPCB) class

The two cited standards, UL 489 and IEEE Std C37.13™, define the MCCB and the LVPCB classes.¹

1.2.1 MCCB types

Because of the very large number of MCCBs which are produced for a great variety of applications, several sub-types of MCCBs are widely recognized within the industry. Two of the more popular sub-types of MCCBs are insulated-case circuit breakers (ICCBs) and miniature circuit breakers (MCBs). These are discussed in more detail below, but it should be noted that because these types are not separately defined within UL 489, the distinguishing characteristics described are usual and commonly provided within the market, but are not guaranteed and may vary from one brand to another.

The two types of MCCBs are as follows:

- a) Miniature circuit breakers
- b) Insulated-case circuit breakers

Each one of these circuit breakers has different design characteristics and, in many cases, different application requirements.

NOTE—UL 1077 defines devices called supplementary protectors which provide some circuit breaker-like functions but are not circuit breakers within the context of applicable North American standards and hence are used to supplement other overcurrent protection within the guidelines prescribed by the National Electrical Code® (NEC®) (NFPA 70®) and UL 1077. This IEEE recommended practice does not cover supplementary protectors.²

MCCBs, as a class, are tested and rated in accordance with UL 489. Their current-carrying parts, mechanisms, and trip devices are completely contained within a molded case of insulating material. MCCBs are available in the widest range of sizes, from the smallest (15 A or less) to the largest (6000 A), and with various interrupting ratings for each frame size. They are characterized generally by fast interruption short-circuit elements. Virtually all MCCBs interrupt fast enough to limit the amount of prospective fault current let-through, and some limit enough current and operate fast enough to be identified as current-limiting circuit breakers. The smaller continuous-current ratings are equipped with thermal-magnetic or magnetic-only trip units. Larger sizes are also available with thermal-magnetic or electronic trip units. With electronic trip units, they can have limited short-delay and ground-fault sensing capability. The cover and base of smaller MCCBs are designed so that the MCCBs cannot be opened for maintenance purposes. The main contacts of MCCBs cannot be removed; however, some MCCBs are available with internal field-installable accessories. MCCBs are available in stationary or plug-in construction with circuit breaker enclosures that can be flush or surface mounted.

Within the MCCB classification there is another group of devices that is known within the industry as MCBs. The term miniature circuit breaker is notable because it is used to describe circuit breakers that are typically 1 in (25.4 mm) or less wide per pole and are commonly used in residential or lighting circuit applications at 120 V, 208 V, and 240 V. This type of circuit breaker often is provided with integral electronic ground fault or arc fault protection in addition to the thermal magnetic overcurrent protection. MCBs do not have a separate or unique designation within the UL 489 standard, and generally are tested as MCCBs per UL 489 requirements.

¹ IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

² Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

ICCBs are also tested and rated in accordance with UL 489. However, they use characteristics of design from both the power and molded-case classes. They are of the larger frame sizes, fast in interruption, but normally not fast enough to qualify as current-limiting circuit breakers. As with MCCBs, ICCB current-carrying parts, mechanisms, and trip units are contained within a molded case of insulating material. The case is designed so that it can be opened for inspection of contacts and arc chutes and for limited maintenance. Most manufacturers offer designs that permit installation or replacement of internal accessories, and some designs permit replacement of the main contacts such that they are partially field maintainable. ICCBs are available in both stationary and drawout construction. They are generally characterized by a two-step stored energy mechanism similar to those designed for LVPCBs, larger frame sizes, and higher short-time withstand ratings than other MCCBs. ICCBs also use electronic trip units and can have short-time capability and ground-fault current sensing.

UL 489 (U.S.) is a tri-national standard, meaning that it has been harmonized with Canadian Standards Association (CSA) C22.2 No. 5 (Canada) and Asociación Nacional de Normalización y Certificación del Sector Eléctrico, A.C. (ANCE) NMX-J-266 (Mexico). A tri-national standard means that all three standards read the same, with the possible exception of a few country-specific requirements. Further, National Electrical Manufacturers Association (NEMA) AB1, the NEMA molded-case circuit breaker standard, now refers to UL 489.

1.2.2 LVPCB types

LVPCBs are tested and rated according to the following standards:

- IEEE Std C37.16™, IEEE Standard for Preferred Ratings, Related Requirements, and Application Recommendations for Low-Voltage AC (635 V and below) and DC (3200 V and below) Power Circuit Breakers.
- IEEE Std C37.17™, IEEE Standard for Trip Devices for AC and General Purpose DC Low Voltage Power Circuit Breakers.
- ANSI Std C37.50, Low-Voltage AC Power Circuit Breakers Used in Enclosures—Test Procedures
- IEEE Std C37.13™, IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.
- IEEE Std C37.14™, IEEE Standard for Low-Voltage DC Power Circuit Breakers Used in Enclosures.
- UL 1066, Low-Voltage AC and DC Power Circuit Breakers Used in Enclosures.

LVPCBs are generally characterized by physically large frame sizes, drawout construction, and the highest short-time withstand ratings of all the types of low-voltage circuit breakers. They have short-time ratings, but they are not fast enough in interruption to qualify as current-limiting. They are rated and tested to satisfy the IEEE C37 series of standard requirements, and they are used primarily in drawout switchgear. When the circuit breaker is removed from its enclosure, the current-carrying parts and operating parts, depending on the design, may be partially or fully accessible for inspection, maintenance, and replacement purposes. Electromechanical trip units were used in the circuit breakers prior to the early 1970s. However, electronic trip units are used in new LVPCBs and are available as upgrades for older units.

1.3 Description of a molded-case circuit breaker

Figure 1 illustrates the internal construction of a typical small MCCB. This typical circuit breaker operates using an over-center toggle, quick-make quick-break mechanism. This mechanism is operated manually to the ON (closed) and OFF (open) positions using the handle. The quick-make quick-break action ensures that the speed at which the breaker contacts are opened or closed is independent of the speed at which the

handle is moved. This toggle mechanism is also trip-free, which means that the circuit breaker cannot be prevented from tripping by holding or locking the handle in the ON position. When the circuit breaker trips open automatically, the handle will assume either an intermediate position between ON and OFF or the OFF position. If the handle moves to the intermediate position, it must be manually moved slightly past the OFF position to reset the mechanism. Instructions for resetting a particular circuit breaker after it trips should be marked on the circuit breaker and/or indicated on the equipment where the circuit breaker is installed. It should be noted that trip-free mechanisms are required for LVPCBs in the appropriate UL, IEEE, and ANSI standards where the performance requirements are prescribed.

Small multi-pole MCCBs may be built by riveting single pole units together (Figure 2) or by housing the individual pole assemblies in a single case (Figure 3). In either case, each pole has its own mechanism and each mechanism is mechanically linked such that all poles open and close simultaneously. Further, the tripping mechanisms are linked such that an overcurrent in one pole will cause all poles to open simultaneously.

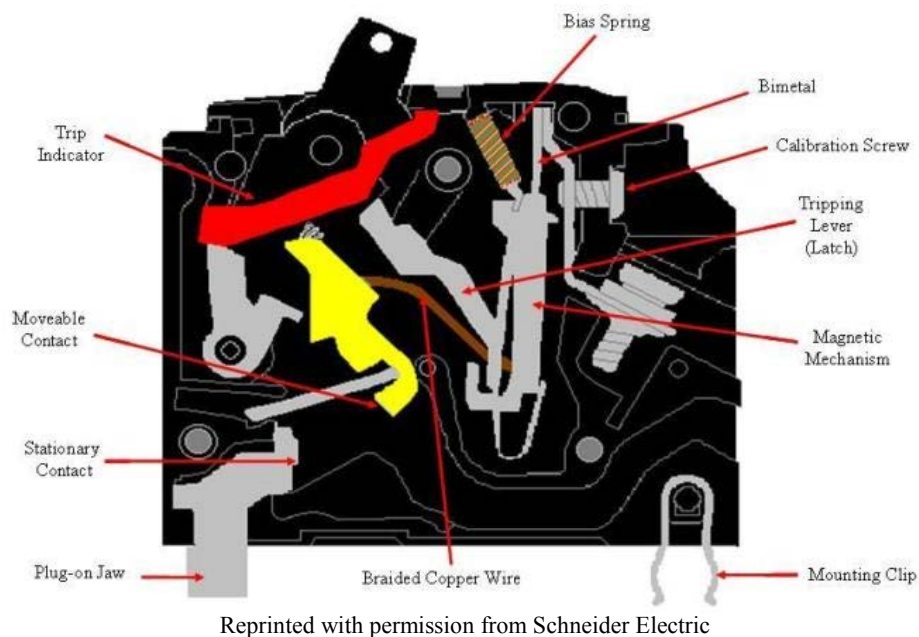


Figure 1—Internal construction of a small MCCB



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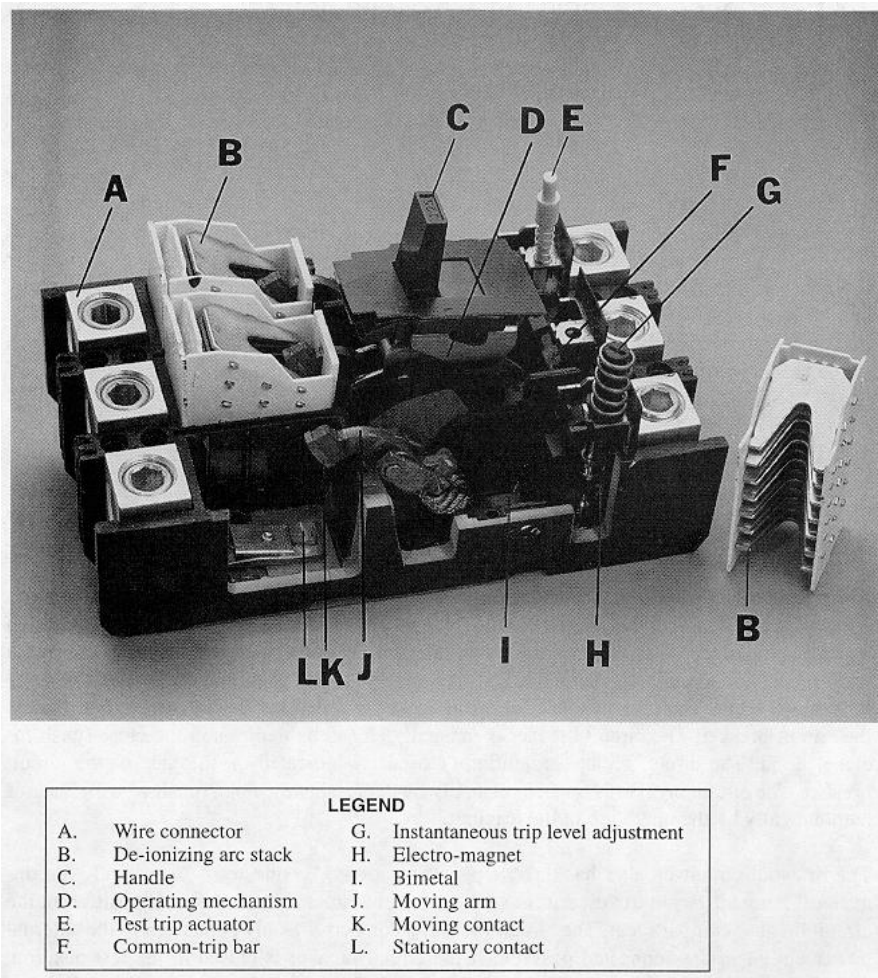
Figure 2—Small multi-pole MCCB, riveted case construction



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Figure 3—Small multi-pole MCCB, single case construction

Figure 4 is a partially disassembled view of a typical larger MCCB. Letters are used to indicate the various elements of the circuit breaker, with a description listed in the legend. This typical circuit breaker operates using an over-center toggle, quick-make quick-break mechanism. This mechanism is operated manually to the ON (closed) and OFF (open) positions using the handle. The quick-make quick-break action ensures that the speed at which the breaker contacts are opened or closed is independent of the speed at which the handle is moved. This toggle mechanism is also trip-free, which means that the circuit breaker cannot be prevented from tripping by holding or locking the handle in the ON position. When the circuit breaker trips open automatically, the handle will assume either an intermediate position between ON and OFF or the OFF position. If the handle moves to the intermediate position, it must be manually moved slightly past the OFF position to reset the mechanism. Instructions for resetting a particular circuit breaker after it trips should be marked on the circuit breaker and/or indicated on the equipment where the circuit breaker is installed.



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Figure 4—Cutaway view of a typical larger MCCB

The following description of the operation of an ICCB starts with the open position. The circuit breaker condition OPEN is indicated on the face of the circuit breaker. To close the circuit breaker, a spring mechanism must be charged. The springs are charged by pulling down and releasing the manual spring charging handle. The spring condition CHARGED is indicated on the face of the circuit breaker. The circuit breaker is manually closed by depressing the close (push-to-close) button. The circuit breaker condition CLOSED is indicated on the face of the circuit breaker. This is referred to as two-step operation. The circuit breaker is opened manually by depressing the open (push-to-trip) lever or automatically by the operation of the trip unit.

1.4 Description of a low-voltage power circuit breaker

Figure 5 is a view of a partially disassembled, manually operated, drawout LVPCB. The open construction permits access to the circuit breaker parts for maintenance and parts replacement. Newer designs such as shown in Figure 5 may not offer the degree of maintenance and repair that older designs did, however, they may not need it due to their longer life expectancy (see Table 3). (Consult the manufacturer for service information.) Numbers are used to indicate the various elements of the circuit breaker. A description of each element is listed in the legend.

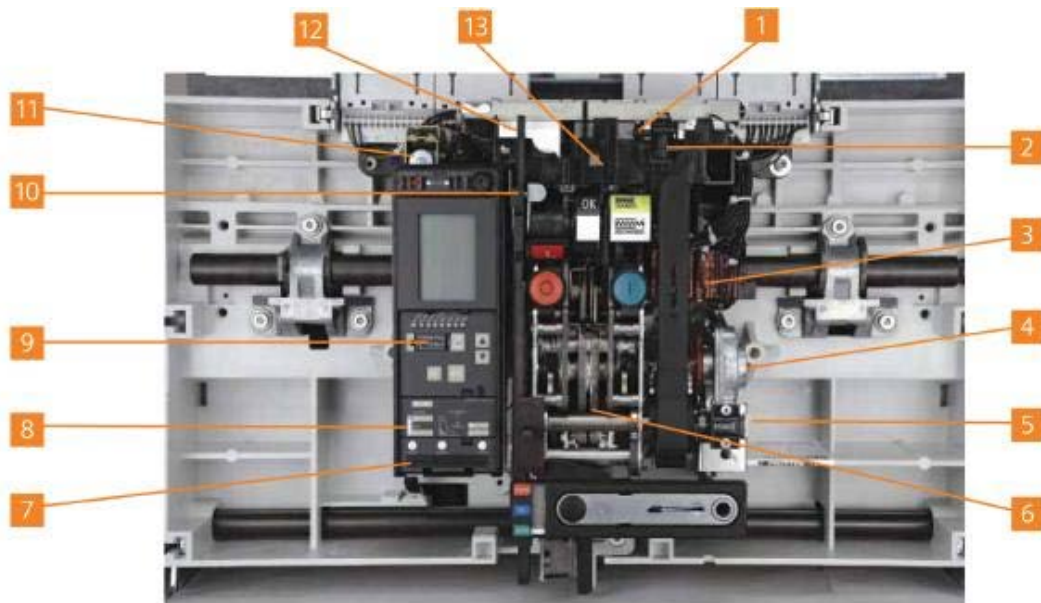
The following description of the operation of the circuit breaker starts with the open position. The circuit breaker condition OPEN is indicated on the face of the circuit breaker. To close the circuit breaker, a spring mechanism must be charged. The springs are charged by pulling down and releasing the manual spring charging handle. The spring condition CHARGED is indicated on the face of the circuit breaker. The circuit breaker is manually closed by depressing the close (push-to-close) button. The circuit breaker condition CLOSED is indicated on the face of the circuit breaker. This is referred to as two-step operation. The circuit breaker is opened manually by depressing the open (push-to-trip) lever or automatically by the operation of the trip unit.

The drawout circuit breaker has three separate positions: CONNECT, TEST, and DISCONNECT. A racking crank or similar is used to move the drawout circuit breaker to each position in the circuit breaker compartment. The circuit breaker's contacts are only connected to the external power circuit in the connected position. If the circuit breaker is closed in the TEST position, there is no effect to the external power circuit. Interlocking prevents moving a closed circuit breaker between these positions or closing it in other than the CONNECT or TEST position. Further optional interlocking prevents inserting circuit breakers of the wrong frame size into a compartment. Primary disconnects and optional secondary disconnects automatically complete the power circuit in the CONNECT position and control circuits in the CONNECT and TEST positions, respectively.



Exterior breaker features

- | | |
|---------------------------------------|--|
| 1. Sliding secondary control contacts | 4. Integral racking handle |
| 2. Spring charging handle | 5. Electronic trip unit with LCD display |
| 3. Centralized operator panel | 6. Arc chutes |



Interior breaker features

- | | |
|--|---|
| 1. Remote closing coil | 8. Optional ground fault module with alarm and trip functions |
| 2. Dual shunt trip or UV release | 9. Interchangeable current rating plug |
| 3. Auxiliary switch | 10. Breaker status sensor (BSS) |
| 4. Automatic charging motor | 11. Bell alarm contact with remote reset |
| 5. Operation counter | 12. Shunt trip coil |
| 6. Riveted breaker operating mechanism | 13. Ready-to-close-contact |
| 7. Electronic trip unit (ETU) | |

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**Figure 5—Low-voltage ac power circuit breaker—drawout type
(shown partially disassembled to show internal features)**

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std C37.17TM, IEEE Standard for Trip Devices for AC and General Purpose DC Low Voltage Power Circuit Breakers.^{3,4}

IEEE Std C37.13TM, IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.

IEEE Std C37.14TM, IEEE Standard for Low-Voltage DC Power Circuit Breakers Used in Enclosures.

IEEE Std C37.16TM, IEEE Standard for Preferred Ratings, Related Requirements, and Application Recommendations for Low-Voltage AC (635 V and below) and DC (3200 V and below) Power Circuit Breakers.

IEEE Std C37.20.1TM, IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

IEEE Std C37.50, IEEE Standard for Switchgear—Low-Voltage AC Power Circuit Breakers Used in Enclosures—Test Procedures.

NFPA 70, National Electrical Code (NEC).⁵

UL 489, Standard for Safety for Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures.⁶

UL 943, Standard for Safety for Ground-Fault Circuit-Interrupters.

UL 1066, Low-Voltage AC and DC Power Circuit Breakers Used in Enclosures.

UL 1077, Standard for Supplementary Protectors for Use in Electrical Equipment.

UL 1699, Standard for Safety for Arc-Fault Circuit-Interrupters.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁷

³ IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>)

⁴ The IEEE standards or products referred to in this clause are trademarks of The Institute of Electrical and Electronics Engineers, Inc.

⁵ NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

⁶ UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://www.global.ihs.com/>).

⁷ *IEEE Standards Dictionary Online* subscription is available at:
http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

adjustable circuit breaker: A circuit breaker that has adjustable time/current tripping characteristics. These may include inverse-time (such as continuous current, long time, and/or short time), instantaneous, and ground-fault. (adapted from UL 489)

alarm switch: A switch that operates to open or close a circuit upon the automatic opening of the circuit breaker with which it is associated. (adapted from UL 489)

authority having jurisdiction (AHJ): An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

NOTE—The phrase authority having jurisdiction or its acronym, AHJ, is used in NFPA documents in a broad manner since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

auxiliary switch: A switch that operates to open or close an auxiliary (control) circuit upon the opening, closing, or tripping of the circuit breaker with which it is associated. (adapted from UL 489)

NOTE—Auxiliary switch contacts are classified as a, b, aa, bb, LC, etc., for the purpose of specifying definite contact positions with respect to the main device.

available short-circuit current: (at a given point in a circuit) The maximum current that the power system can deliver through a given circuit to any negligible-impedance short circuit applied at the given point, or at any other point that will cause the highest current to flow through the given point. *See also:* **prospective fault current.**

circuit breaker: A device designed to open and close a circuit by non-automatic means and to open the circuit automatically on a predetermined overcurrent without damage to itself when properly applied within its rating. (adapted from the NEC) *Syn:* **low-voltage circuit breaker.**

continuous load: A load where the maximum current is expected to continue for three hours or more. (adapted from the NEC)

coordination (selective): The selection and/or setting of protective devices to provide coordinated protection of system components and circuits. In terms of overcurrent protection that means that minimum circuit interruption is achieved for different types and magnitudes of faults and over-currents. A system may be said to be selective when coordination is achieved. The activity of studying systems characteristics and determining optimum device settings and selection is called a coordination study.

current-limiting circuit breaker: A circuit breaker that does not use a fusible element and that when operating within its current-limiting range limits the let-through I^2t to a value less than the I^2t of a 1/2 cycle wave of the symmetrical prospective current. (adapted from UL 489) *See also:* **current-limiting overcurrent protective device.**

current-limiting overcurrent protective device: A device that, when interrupting currents in its current-limiting range, reduces the current flowing in the faulted circuit to a magnitude substantially less than that obtainable in the same circuit if the device were replaced with a solid conductor having comparable impedance. (adapted from the NEC) *See also:* **current-limiting circuit breaker.**

drawout-mounted circuit breaker: An assembly of a circuit breaker together with a supporting structure so constructed that the breaker is supported and can be moved between the main circuit connected and the disconnected positions without unbolting connections or mounting supports. The stationary portion of the drawout assembly includes self-supporting primary circuit terminals and may include an interlocking means that permits movement of the breaker between the main circuit connected and the disconnected positions only when the breaker contacts are in the open position. (adapted from UL 489)

dynamic impedance: The arc impedance introduced into a circuit by the opening of the circuit breaker contacts during current interruption. (adapted from NEMA AB 1)

electrical operator: A controlling device that is used to open, close, and reset a circuit breaker. (adapted from UL 489)

NOTE—The term *motor operator* is sometimes used when the operating device is a motor.

electronic trip unit: A self-contained portion of a circuit breaker that senses the condition of the circuit breaker electronically and that actuates the mechanism that opens the circuit breaker contacts automatically.

NOTE—Where the term *electronic trip unit* is used in this document, the alternate terms *solid state trip unit* and *static trip unit* are commonly used in literature.

frame size: A term applied to a group of circuit breakers of similar physical configuration or continuous current rating. Frame size is expressed in amperes and corresponds to the largest continuous ampere rating available in the group. The same frame size designation may be applied to more than one group of circuit breakers. (adapted from UL 489)

frame: As applied to circuit breakers, that portion of an interchangeable trip unit circuit breaker remaining when the interchangeable trip unit is removed. (adapted from UL 489)

ground-fault delay: An intentional time delay in the tripping of a circuit breaker when a ground fault occurs. (adapted from NEMA AB 1)

ground-fault pickup: The nominal value of the ground-fault current at which the ground-fault delay function is initiated. (adapted from UL 489)

ground-fault protection of equipment: A system intended to provide protection of equipment from damaging line-to-ground fault currents by operating to cause a disconnecting means to open all ungrounded conductors of the faulted circuit. This protection is provided at current levels less than those required to protect conductors from damage through the operation of a supply-circuit overcurrent device. (adapted from the NEC)

I^2t : An expression related to the energy available as a result of current flow over time. Demonstrates that the energy input from current over time is proportional to the square of the current and has a linear relationship with time.

instantaneous pickup: The nominal value of current at which an adjustable circuit breaker is set to trip instantaneously. (adapted from UL 489)

instantaneous trip: (as applied to circuit breakers) A qualifying term indicating that no delay is purposely introduced in the tripping action of the circuit breaker. (adapted from the NEC)

instantaneous-trip-only circuit breaker: A circuit breaker intended to provide short-circuit protection only. Although acting instantaneously under short-circuit conditions, instantaneous-trip breakers may be permitted to include a transient damping action to ride through initial motor transients. (adapted from UL 489)

insulated-case circuit breaker (ICCB): A circuit breaker that is assembled as an integral unit in a supporting and enclosing housing of insulating material and with a two-step stored energy mechanism.

integrally-fused circuit breaker: A circuit breaker in which coordinated fuses are connected in series with the release (trip) elements of the circuit breaker and are mounted within the housing of the circuit breaker. (based on 2.36 of UL 489)

interrupting rating: The highest current at rated voltage that a device is intended to interrupt under standard test conditions. (adapted from the NEC)

inverse time: (as applied to circuit breakers) A qualifying term indicating that there is purposely introduced a delay in the tripping action of the circuit breaker, which delay decreases as the magnitude of the current increases. (adapted from the NEC)

I_p : *See:* **peak current.**

long-time delay: An intentional time delay in the overload tripping of an adjustable circuit breaker's inverse time characteristic. (adapted from UL 489)

long-time pickup: The current at which the long-time delay function is initiated. (adapted from UL 489)

low-voltage power circuit breaker (LVPCB): A mechanical switching device capable of making, carrying, and breaking currents under specified normal and abnormal circuit conditions. An LVPCB is designed per the requirements of IEEE Std C37.13, IEEE Std C37.14, and tested per procedures in ANSI C37.50.

making current release (MCR): A trip function used to ensure that a circuit breaker does not attempt to close into a fault of a magnitude above its close and latch capability.

molded-case circuit breaker (MCCB): A circuit breaker that is assembled as an integral unit in a supporting and enclosing housing of insulating material. MCCBs are most often available in two or three pole versions and are typically rated from 240 V to 600 V. (adapted from and IEEE Std C37.100 [B13])⁸

molded-case switch: A device designed to open and close a circuit by nonautomatic means, assembled as an integral unit in a supportive and enclosed housing of insulating material. *Syn:* **nonautomatic switch** (deprecated). (adapted from UL 489)

overcurrent: Any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload, short circuit, or ground fault. (adapted from the NEC) *See also:* **overload.**

overload: Operation of equipment in excess of normal, full-load rating or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload. (adapted from the NEC) *See also:* **overcurrent.**

panelboard: A single panel or group of panel units designed for assembly in the form of a single panel, including buses and automatic overcurrent devices, and equipped with or without switches for the control of light, heat, or power circuits; designed to be placed in a cabinet or cutout box placed in or against a wall, partition, or other support; and accessible only from the front. (adapted from the NEC) *See also:* **switchboard.**

peak current: The maximum instantaneous current that flows in a circuit, designated I_p . (adapted from UL 489)

⁸ The numbers in brackets correspond to those of the bibliography in Annex A.

peak let-through current: The highest current flowing in the circuit after the inception of the fault that the circuit breaker and the protected system must withstand, expressed as an instantaneous rather than a root-mean-square (rms) value.

pickup: The root-mean-square (rms) current at which a circuit breaker tripping function is initiated. (adapted from NEMA AB 1)

prospective fault current: The current that would flow during a short circuit if the circuit breaker and the wires used for its connection were replaced by a solid conductor of negligible impedance. (adapted from UL 489) *See also:* **available short-circuit current.**

rated short-time withstand current: **(A)** The maximum root-mean-square (rms) total current that a circuit breaker can carry momentarily without electrical, thermal, or mechanical damage or permanent deformation. The current shall be the rms value, including the dc component, at the major peak of the maximum cycle as determined from the envelope of the current wave during a given test time interval. (adapted from IEEE Std C37.100™-1992 [B13]) **(B)** That value of current assigned by the manufacturer that the device can carry without damage to itself under prescribed conditions. (adapted from NEMA AB 1) *Syn:* **withstand rating, short-time rating.**

rating plug: An interchangeable module used with some electronic trip units that, together with the sensor, sets the current rating range of the circuit breaker.

NOTE—A 1200 A frame may contain an 800 A sensor, fixing the maximum rating that can be configured for the unit at 800 A adjustable by the following kind of settings. By installing a 600 A rating plug, the adjustable rating is correspondingly 600 A multiplied by the long-time pickup adjustment [i.e., the long-time pickup may be adjusted to 0.9, and the ampere rating or setting is $(0.9 \times 600 \text{ A}) = 540 \text{ A}$]. Rating plugs may also include user adjustments. Some AHJ will use the rating plug to determine the smallest conductors sized that may be employed in the circuit.

release: A device mechanically connected within the circuit breaker that initiates the tripping function of a circuit breaker. (adapted from NEMA AB 1)

root-mean-square (rms) sensing: A term commonly used to indicate the sensing of root-mean-square (rms) value current rather than instantaneous or peak values, as by a circuit breaker trip unit.

selective coordination: *See:* **coordination (selective).**

sensor: (as applied to a circuit breaker with an electronic trip unit) A current sensing element such as a current transformer, air core sensor (Rogowski coil), or other type of sensing mechanism within a circuit breaker frame that provides a signal used by the electronics to determine current flowing through the protected circuit. The sensor will usually have a current rating less than or equal to the frame size and will provide the sensing function for a specific group of current ratings within the frame size. Sensors may be tapped to provide multiple ranges, particularly in older LVPCB and trip kits used to upgrade the trip operation of older circuit breakers.

series rating: The interrupting rating of a tested combination of a line-side (main) overcurrent protective device and a load-side (branch) circuit breaker in which the interrupting rating of the combination is greater than the interrupting rating of the branch circuit breaker. The interrupting rating of the series combination does not exceed the interrupting rating of the main overcurrent protective device. *Syn:* **series-connected rating.** Series ratings are obtained through UL 489 test protocols and are UL recognized.

NOTE—See UL Recognized Component Directory [B26].

setting: (of a circuit breaker) The value of current, time, or both at which an adjustable circuit breaker is set to trip. (adapted from the NEC)

short circuit: An abnormal connection (including an arc) of relatively low impedance, whether made accidentally or intentionally, between two points of different potential. (adapted from IEEE Std C37.100 [B13])

short-time current: The current carried by a device, an assembly, or a bus for a specified short-time interval. (adapted from IEEE Std C37.100 [B13]) *See also:* **rated short-time withstand current; short-time rating.**

short-time delay phase or ground trip element: A direct-acting trip device element that functions with a purposely delayed action (measured in milliseconds). (adapted from IEEE Std C37.100 [B13])

short-time delay: An intentional time delay in the tripping of a circuit breaker that is above the overload pickup setting.

short-time pickup: The current at which the short-time delay function is initiated. (adapted from UL 489)

short-time rating: A rating applied to a circuit breaker that, for reason of system coordination, causes tripping of the circuit breaker to be delayed beyond the time when tripping would be caused by an instantaneous element. (adapted from UL 489) *See also:* **rated short-time withstand current; short-time current.**

shunt trip device: A trip mechanism energized by a source of voltage that may be derived either from the main circuit or from an independent source. (adapted from UL 489)

stored-energy operation: Operation by means of energy stored in the mechanism before the completion of the operation and sufficient to complete it under predetermined conditions. (adapted from IEEE Std C37.100 [B13])

switchboard: A type of switchgear assembly that consists of one or more panels with electric devices mounted thereon and associated framework. Low-voltage switchboards are listed per UL 891.

NOTE—Switchboards may be classified by function, that is, power switchboards or control switchboards. Both power and control switchboards may be further classified.

switchgear assembly: A switchgear assembly is a type of switchgear (indoor or outdoor) that is constructed from components including, but not limited to, one or more of the following: switching, interrupting, control, metering, protective, and regulating devices, together with supporting structures, enclosures, conductors, electric interconnections, and accessories. Low-voltage power switchgear assemblies are designed in accordance with IEEE Std C37.20.1 and may be listed per UL 1558.

switchgear: A general term covering switching and interrupting devices and their combination with associated control, metering, protective, regulating devices, and assemblies of these devices with associated interconnections, accessories, enclosures, and supporting structures, used primarily in connection with the generation, transmission, distribution, and conversion of electric power. Switchgear is designed in accordance with the IEEE C37 series of standards.

transient recovery voltage (TRV): The voltage transient that occurs across the terminals of a pole of a switching device upon interruption of the current. (adapted from IEEE Std C37.100 [B13])

trip unit: A self-contained portion of a circuit breaker that actuates the mechanism that opens the circuit breaker contacts automatically. (adapted from UL 489)

tripping: The opening of a circuit breaker by actuation of the release mechanism. (adapted from UL 489)

NOTE—The terms *trip device* and *tripping device* are used in literature as alternative terms for *trip unit*.

undervoltage trip device: A trip mechanism that causes a circuit breaker to open automatically if the voltage across the terminals of the trip coil falls below a predetermined value. (adapted from UL 489) *Syn:* **undervoltage release.**

withstand current: *See:* **rated short-time withstand current.**

withstand rating: *See:* **rated short-time withstand current.**

zone selective interlocking: A function provided for rapid clearing while retaining coordination. The function requires an interconnection between trip units or relays that signals the upstream device that the downstream device has sensed the fault current and is reacting to it. By means of intercommunication between the devices, the instantaneous, short-time delay and/or ground fault elements in the upstream device may be delayed sufficiently to allow the downstream device to clear. The one nearest the fault trips with a selected time delay while signaling the supply-side circuit breaker(s) to delay for an additional predetermined period. Zone selective interlocking is commonly available in modern electronic trip and modern electronic relays. *Syn:* **zone interlocking; selective interlocking.**

NOTE—In-zone: Overcurrent devices are implemented to protect a specific set of conductors. Those conductors, and equipment or devices directly connected to those conductors, are considered to be the protected zone for the overcurrent device. A fault on those conductors or devices is considered to be an in-zone fault for the overcurrent device. A fault that is in the protection zone of a downstream overcurrent device is considered to be an out-of-zone fault.

3.2 Acronyms and abbreviations

The following acronyms and abbreviations are commonly used in marking and designating circuit breaker ratings.

40 °C	Designates a circuit breaker that is acceptable for use in ambient temperatures up to 40 °C.
AIC	Amperes interrupting capacity. Maximum current a protective device is capable of interrupting, namely, its interrupting rating. May be found in manufacturer's literature. See also: AIR.
AIR	Amperes interrupting rating. Shortened term marked on some small circuit breakers with the interrupting rating.
CTL	A Class CTL circuit breaker, because of its size of configuration in conjunction with the physical means provided in Class CTL panelboards, prevents more circuit breaker poles from being installed than the number for which the assembly is designed and rated. A Class CTL panelboard is a circuit-limited lighting and appliance panelboard as referenced in Section 408.14 to Section 408.34 in the 2005 and earlier editions of the NEC. Both half-size and full-sized circuit breakers may be installed.
HACR	Heating, air conditioning, and refrigeration. Designates compliance with the special requirements of Section 430.53(C)(3) of the NEC, as listed for group installation for use with heating, air conditioning, and refrigeration equipment. A circuit breaker with this marking is suitable for use with equipment marked to indicate that an HACR circuit breaker is acceptable.
HID	High-intensity discharge. Indicates construction suitable for switching high-intensity discharge lighting loads.
SWD	Switching duty. Designates compliance with requirements for circuit breakers used as switches on fluorescent lighting circuits as indicated in Section 240.83(D) of the NEC.

4. Rating and testing

4.1 Relevance of rating and testing

This chapter provides information on rating and testing of circuit breakers that will be helpful to electrical engineers in choosing low-voltage circuit breakers for an application. Ratings assigned to circuit breakers are determined by the testing done to prove their design capabilities. Therefore, a discussion of the testing requirements of the different classes of circuit breakers is fundamental to understanding their capabilities.

Other influences, such as the National Electrical Code (NEC) (NFPA 70-2011), industry practices, and environmental considerations can also affect circuit breaker choices. These are also discussed in areas where they relate to testing requirements. Application considerations such as choosing the type of trip unit, the type of time-current-characteristic, and the continuous current and interrupting ratings to satisfy coordination requirements are the subjects of other clauses of this recommended practice.

4.2 The ideal circuit breaker

The ideal circuit breaker (not realizable) would have no internal impedance and would carry current with no voltage drop when closed; therefore, the circuit breaker would not produce any heat during operation. It would interrupt any overcurrent it was called on to interrupt without experiencing contact erosion, and structurally, it would be able to withstand the pressure and heat of interruption and the magnetic forces produced by the flow of fault current through it. Its connectors would be firmly attached to the circuit breaker terminals and would hold the external circuit conductors in place regardless of the amount of fault current flow. It would provide perfect electrical isolation of the load from the normal system voltage when open, and it would be able to provide these functions indefinitely regardless of the environment.

4.3 The practical circuit breaker

Circuit breakers do not, of course, perform exactly in the fashion described in 4.2. They have internal impedance, and therefore, they develop a small voltage drop while carrying current. The product of the resistive voltage drop and the current is a measure of power loss, which is manifested as heat in the circuit breaker during normal operation. The consequence is that practical circuit breakers warm up during operation.

When properly applied within their ratings and when they are in good operating condition, practical circuit breakers can interrupt any overcurrent that occurs in the circuit in which they are applied. They can do this without undue contact erosion and can withstand the pressure and heat of interruption as well as the magnetic forces produced by fault current. The process of interruption will not damage the operating mechanism, trip unit, or supporting frame. As their contacts do experience some erosion, they can only perform a limited number of switching and interrupting operations without maintenance. Circuit breakers that cannot be maintained should be replaced whenever wear and tear reach certain limits. Properly sized and properly torqued connectors attached to the circuit breaker terminals can hold conductors firmly in place. That is, the connectors must fit the circuit breaker terminals, the connectors must be compatible with the conductor material (AL, or CU, or AL/CU), and the conductor stranding and compression must be compatible with the connector.

Circuit breakers can provide adequate disconnecting capability to isolate the load from recovery voltage transients, surges, and normal voltage, and they can provide adequate service.

4.4 Basic circuit breaker selection criteria

The selection of a circuit breaker for any given duty must be based at a minimum on an assessment of its ability to perform the following basic functions:

- a) To carry the required current without overheating (i.e., it should have the correct current rating)
- b) To switch and isolate or disconnect the load from the source at the given system voltage (i.e., it should have the correct voltage rating)
- c) To interrupt any abnormally high operating current or short-circuit current likely to be encountered during operation (i.e., it should have the correct interrupting rating) and to do so without extensive damage to the electrical equipment of the circuit
- d) To be able to perform these functions over an acceptably long period of time under the operating and environmental conditions that will actually prevail in the application (i.e., it should have the correct mounting provisions, enclosure, and operating endurance and have the required accessories for operation in the environment in which it is applied)

The degree to which a circuit breaker can satisfy these requirements is a measure of its applicability for a function. A circuit breaker's rating indicates these capabilities to the user because rating is established by proof testing. Hence, an understanding of how a circuit breaker is tested and given its rating will give insight into its applicability for any function.

Additional selection criteria should be considered when selecting circuit breakers. Regulatory or safety considerations may make these considerations mandatory. The additional criteria are:

- a) Selective capability within the intended application
- b) Arc flash related performance

4.5 The role of industry standards

The primary vehicle for ensuring commonality in performance among circuit breakers of the same rating produced by different manufacturers is a product standard. Standards represent the consensus of manufacturers, testing organizations, users, and others about what a given product should be able to do. Standards establish the design tests that each manufacturer must perform and pass to claim a rating and to be in compliance with that standard. Some standards include requirements for periodic follow-up testing that, in effect, continues to sample the capabilities of newly manufactured circuit breakers. This testing assures that they maintain the capabilities of their product ratings. Standards also provide for monitoring the quality of the materials used in the construction of circuit breakers and the quality of the workmanship in the manufacturing process.

As stated, standards requirements for the different classes of circuit breakers establish a basis for *minimum* performance. Circuit breakers may prove by test to perform better than their product ratings indicate, but they can never be permitted to perform worse. The user, however, may never assume that a circuit breaker can perform better than its rating indicates and should realize that there are manufacturing variations among mass-produced products. The levels of performance required by the standards for the minimum acceptable performance of different classes of circuit breakers will be the primary references in the discussion that follows.

Circuit breaker performance tested within standard guidelines is tested in laboratory conditions with test protocols that are expected to simulate or exceed real application situations. However, real applications may expose devices to conditions that are not explicitly tested under standard guidelines. When application conditions vary significantly from those defined for the circuit breakers, the circuit breaker manufacturer should be consulted to determine suitability for the intended application and if any specific performance deterioration or change needs to be considered.

4.6 The role of safety and industry codes

Safety and industry code requirements have evolved over the years. These codes reflect experience in actual application over time. The Occupational Safety and Health Act (OSHA) [B19] is the primary legal safety code in the United States, and the NEC is the primary safety code for installations. The NEC is a model code, and to be effective, must be adopted by an authority having jurisdiction (AHJ) either amended or unamended (see NEC Article 100 for the definition of authority having jurisdiction). However, it can be ignored by local bodies and it can be modified.

Other safety standards are the National Electrical Safety Code[®] (NESC[®]) (Accredited Standards Committee C2) [B1] sponsored by IEEE, NFPA 70B [B17], and NFPA 70E [B18]. Industry practices vary between industries and may vary from location to location in the same industry. The NEC and other industry codes may either make use of available circuit breaker product features, or they may influence the development of them for some applications. The feature of the sealable cover over the trip adjusting mechanism of a circuit breaker, described later, indicates how code provisions can affect product design and installation economics.

In Canada, the electrical installation code is CSA C22.1, Canadian Electrical Code Part 1 [B2], which is adopted by the provinces much like the NEC is adopted by the states or local jurisdictions in the United States. Canada does not have a national health and safety act; rather the individual provinces have their own laws such as the Ontario Health and Safety Act and the Ontario Occupational Health and Safety Regulations for Industrial Establishments.

4.7 Comparison of testing requirements

In most cases, a meaningful one-to-one comparison of test procedures will not be possible. It will be seen that tests of different types of circuit breakers differ, and without the exact testing, comparisons of the severity of tests can be made only subjectively. There are also some local differences in interpretation of the requirements of the NEC and other specific industry safety codes that make them also somewhat subjective. Only consideration and evaluation of the whole set of application requirements will permit a confident selection of a type of circuit breaker to be made. This chapter addresses many of the details that should be evaluated.

4.8 Circuit breaker classes and types

For low-voltage circuit protection in the North America, circuit breaker designs and tests are based on the requirements of three standards organizations: the American National Standards Institute (ANSI), UL, and NEMA. The two classifications of circuit breakers these organizations define are as follows:

- Molded-case circuit breaker class
- Low-voltage power circuit breaker class

Three types of circuit breakers are based on the two classifications above. The insulated-case type of circuit breakers is derived from the molded-case circuit breaker class. The three types of circuit breakers are as follows:

- Molded-case circuit breakers (MCCBs)
- Insulated-case circuit breakers (ICCBs)
- Low-voltage power circuit breakers (LVPCBs)

Some salient features of these types of circuit breakers are as follows:

MCCBs, as a class, are those tested and rated according to UL 489 and whose current-carrying parts, mechanisms, and trip devices are completely contained within a molded case of insulating material. MCCBs are available in the widest range of sizes, from the smallest (15 A or less) to the largest (6000 A of the ICCB type) and with various interrupting ratings for each frame size. They are characterized generally by fast interruption short-circuit elements. With electronic trip units, they can have limited short-delay and ground-fault sensing capability. Virtually all MCCBs interrupt fast enough to limit the amount of prospective fault current let-through, and some limit enough current and operate fast enough to be identified as current-limiting circuit breakers. MCCBs are not designed to be field maintainable.

ICCBs are also rated and tested according to UL 489. However, they use characteristics of design from both the power and molded-case classes. They are of the larger frame sizes, fast in interruption, but normally not fast enough to qualify as current-limiting circuit breakers. ICCBs also use electronic trip units and can have short-time capability and ground-fault current sensing. They use two-step stored energy operating mechanisms similar to those designed for LVPCBs, and their design is such that they are partially field maintainable.

LVPCBs are rated and tested to satisfy IEEE C37 standard requirements and are used primarily in drawout switchgear. They are generally characterized as being the largest in physical size. They have short-time ratings, but they are not fast enough in interruption to qualify as current-limiting. Depending on their design, LVPCBs may be partially or fully maintainable in the field.

The IEEE C37 series of standards was jointly developed by IEEE and NEMA and apply to LVPCBs. UL 489 was developed by UL in consultation with manufacturers and users, and it applies to ICCBs and MCCBs.

4.9 Generalized application considerations

Relative to the physical details of design and application, MCCBs are most often applied fixed-mounted; however, drawout mechanisms have been designed for some of the largest ones, and plug-in mechanisms have been designed for some of the smaller ones. Larger MCCBs are designed to use interchangeable trip units. They can be either thermal-magnetic trip units using bimetallic overload elements and electromagnetic overcurrent trips, or they can be electronic trip units incorporating electrical analog and/or digital logic circuits to calculate current levels and initiate tripping functions.

Most low-voltage circuit breakers are able to operate overcurrent protection function in a self-power mode. The required power is derived from the normal, overload, or fault current via current transformers within the circuit breaker. The current transformers may or may not be the same ones used for current measurement. The same circuit breakers, particularly ICCBs and LVPCBs and some large MCCBs also may include provisions for control power connections which may be used to provide power.

ICCBs are used primarily in fixed-mounted switchboards, but because of their size and weight, they are frequently mounted using drawout mechanisms. ICCBs are designed primarily to use interchangeable state-of-the-art electronic trip units.

Traditionally, it is expected that LVPCBs are more maintainable than ICCBs, and ICCBs are more maintainable than traditional MCCBs. However, modern circuit breaker designs are erasing some of these differences while simultaneously providing devices with potentially less need for maintenance due to improvements in device life and operations capability.

LVPCBs are always used in enclosures, and because of their large size and weight, they are essentially always applied in drawout construction. Fixed mounting is an option rarely used. Drawout mechanisms not only minimize the work required in circuit-breaker installation and maintenance, but they also facilitate

rapid change out, which minimizes system downtime. This feature is especially important when the circuit breaker to be changed out is a main and a building or plant shutdown is necessary to change it. Drawout mechanisms also facilitate the performance of regular field inspection and maintenance services.

LVPCBs can use a variety of trip units. Some of the latest versions of electronic trip units used on LVPCBs are also used in large MCCBs and ICCBs. Significant differences in the total operating times of different circuit breakers using the same types of trip units are accounted for in specific time-current curves (TCCs) published for the different circuit breaker and trip unit combinations.

Low-voltage circuit-breaker TCCs are drawn to represent the entire circuit-breaker protection system and include the various components that make up system operation:

- a) Sensing variability
- b) Algorithm or sensing mechanism operation
- c) Mechanical operation time and variation
- d) Clearing time and variation (under worst case trip conditions)

This means that the circuit-breaker TCC is a complete representation of the circuit-breaker system operation.

4.10 References on rating and application

For new equipment, the latest version of standards should always be used for circuit breaker information. For older equipment, the version of the standards that was in effect when the circuit breaker was manufactured should be referenced.

Preferred ratings and application recommendations for LVPCBs are given in IEEE Std C37.16. The standards for low-voltage ac power circuit breakers used in enclosures are given in IEEE Std C37.13, and the standards for low-voltage dc power circuit breakers used in enclosures are given in IEEE Std C37.14. Test procedures for LVPCBs used in enclosures are given in ANSI C37.50. Application guide factors are discussed in IEEE Std C37.13, and unusual service conditions for LV switchgear are discussed in IEEE Std C37.20.1. LVPCBs are generally UL Listed and can be UL Labeled per UL 1066. Ratings and test procedures for MCCBs and ICCBs are found in UL 489.

4.11 Endurance considerations

Table 1, Table 2, and Table 3 summarize some specific mechanical and electrical endurance test parameters. The information in these tables is taken from ANSI Std C37.50 and UL 489. As the tests or test conditions are different, these standards do not lend themselves to a one-to-one comparison. It is necessary to make subjective judgments to determine which test procedure might be more severe than another.

Although choices may be made by subjective judgment of test procedures, an alternative method is to follow established practices that have a history of long-term successful performance. Fortunately, information on these practices is often available in the engineer's own facility, and if it is not, references such as IEEE Std 493™ [B9], which discusses reliability in general and contains sets of data that can be of assistance in decision making, can be consulted. The comments in this clause may be sufficient to resolve some questions on evaluation, but sometimes they may be sufficient only to indicate a direction for further, more detailed engineering investigation.

Other aspects of application, such as the size or weight of a circuit breaker or its physical placement in a building or facility, spares availability or its maintenance requirements, and not factors directly pertaining to electrical rating and testing, can have an impact on the selection.

Table 1—AC circuit breaker endurance test parameters

Parameter	UL 489-2013	ANSI C37.50-2012
Enclosure	Smallest individual or open if mounted on metal plate	Minimum dimension test enclosure
Current	Rated	Rated
Voltage	100%-105% rated	100%-105% rated max (254 V, 508 V, or 635 V)
Power factor (ac)	0.75-0.80	0.85 max
Time constant (dc)	Time constant not less than 3 ms	Not covered
Frequency	48 Hz-62 Hz	48 Hz-72 Hz
Ambient	Not defined	10 °C-40 °C
Ground fuse	30 A	30 A or 10 AWG (copper)

NOTE—The electrical endurance test parameters for dc circuit breakers are found in IEEE Std C37.14.

Source: UL 489-2013 and ANSI C37.50-2012

Table 2—Endurance test operations for MCCBs

Maximum frame size in amperes	Number of cycles of operation			
	Per minute ^a	With current	Without current	Total
100	6	6000	4000	10 000
150	5	4000 ^b	4000	8000 ^b
225	5	4000	4000	8000
600	4	1000	5000	6000
800	1	500	3000	3500
1200	1	500	2000	2500
2500	1	500	2000	2500
6000	1 ^c	400	1100	1500

^aFor circuit breakers rated more than 800 A, the endurance test may, at the option of the manufacturer, be conducted in groups of 100 load operations. No-load operations may be conducted between groups of load operations at the option of the manufacturer.

^bWhere tests are required on samples having ratings of 100 A or less, 250 V or less, the number of operations shall be the same as for the 100 A frame.

^cRate of operation: 1 cycle/minute for first 10 operations; thereafter in groups of 5, at 1 cycle/minute, with an interval between groups that is agreeable to the submitter and the testing agency.

Source: Table 7.1.5.1 of UL 489-2013

Table 3—Circuit breaker mechanical/electrical endurance test comparison

Frame size (Amperes)	Number of cycles of operation									
	Per hour		Between servicing ^d		With current		Without current		Total	
	UL 489-2013 ^a	IEEE Std C37.16-2009	UL 489-2013	IEEE Std C37.16-2009	UL 489-2013	IEEE Std C37.16-2009	UL 489-2013	IEEE Std C37.16-2009	UL 489-2013	IEEE Std C37.16-2009
100	360	—	See Footnote d	—	6000	—	4000	—	10 000	—
150	300	—	See Footnote d	—	4000 ^b	—	4000	—	8000 ^b	—
225	300	—	See Footnote d	—	4000	—	4000	—	8000	—
600	240	30	See Footnote d	1750	1000	2800	5000	9700	6000	12 500
800	60	30	See Footnote d	1750	500	2800	3000	9700	3500	12 500
1200	60	—	See Footnote d	—	500	—	2000	—	2500	—
1600	—	30	—	500	—	800	—	3200	—	4000
2000	—	30	—	500	—	800	—	3200	—	4000
2500	60	—	See Footnote d	—	500	—	2000	—	2500	—
3000	—	30	—	250	—	400	—	1100	—	1500
3200	—	30	—	250	—	400	—	1100	—	1500
4000	—	30	—	250	—	400	—	1100	—	1500
5000	—	30	—	250	—	400	—	1100	—	1500
6000	60 ^c	30	See Footnote d	250	400	400	1100	1100	1500	1500

^aFor circuit breakers rated more than 800 A, the endurance test may, at the option of the manufacturer, be conducted in groups of 100 load operations. No-load operations may be conducted between groups of load operations at the option of the manufacturer.

^bWhere tests are required on samples having ratings of 100 A or less, 250 V or less, the number of operations is to be the same as for the 100 A frame.

^cRate of operation: 1 cycle per minute for first 10 operations; thereafter in groups of 5, at 1 cycle per minute, with an interval between groups that is agreeable to the submitter and the testing agency.

^dServicing is NOT permitted. Servicing means adjusting, cleaning, lubricating, and tightening.

Sources: UL 489-2013 (Table 7.1.5.1 Endurance Test Operations) and IEEE Std C37.16-2009

4.12 AC circuit breaker voltage rating considerations

MCCBs, ICCBs, and LVPCBs use the same standard nominal system voltages of 600 V, 480 V, and 240 V. However, UL 489-listed circuit breakers have additional rated voltages of 120 V, 120/240 V, 277 V, 347 V, 480Y/277 V, and 600Y/347 V, and LVPCBs have maximum voltages. A few comments on these considerations can be very instructive. Slash rated breakers are suitable for use only on solidly grounded systems.

First, for MCCBs and ICCBs, the nominal voltage levels are maximum “not to exceed” voltages, whereas LVPCBs, on the other hand, have assigned “maximum” voltages of 254 V ac, 508 V ac, and 635 V ac. Second, the slash marks (/) between some voltage ratings have significance to circuit breaker design, application, and testing. NEC-2011 Section 240.85 refers to straight and slash voltage marking in an informational note, which is paraphrased as follows:

A circuit breaker with a straight voltage marking, e.g., 240 V or 480 V, may be applied in a circuit in which the nominal voltage between any two conductors does not exceed the circuit breaker’s voltage rating; except that a two-pole circuit breaker is not suitable for protecting a 3-phase corner-grounded delta circuit unless it is marked 1-phase/3-phase to indicate such suitability.

A circuit breaker with a slash rating, e.g., 120/240 V or 480Y/277 V, may be applied in a solidly-grounded circuit in which the nominal voltage-to-ground from any conductor does not exceed the lower of the two values of the circuit breaker’s voltage rating, and the nominal voltage between any two conductors does not exceed the higher value of the circuit breaker’s voltage rating.

Voltage is a sensitive factor in interruption, and circuit-breaker voltage rating is a significant factor in applications. That significance can be seen most readily in that different interrupting ratings are assigned to the same circuit breaker at different system voltages. The ratings are proven in testing.

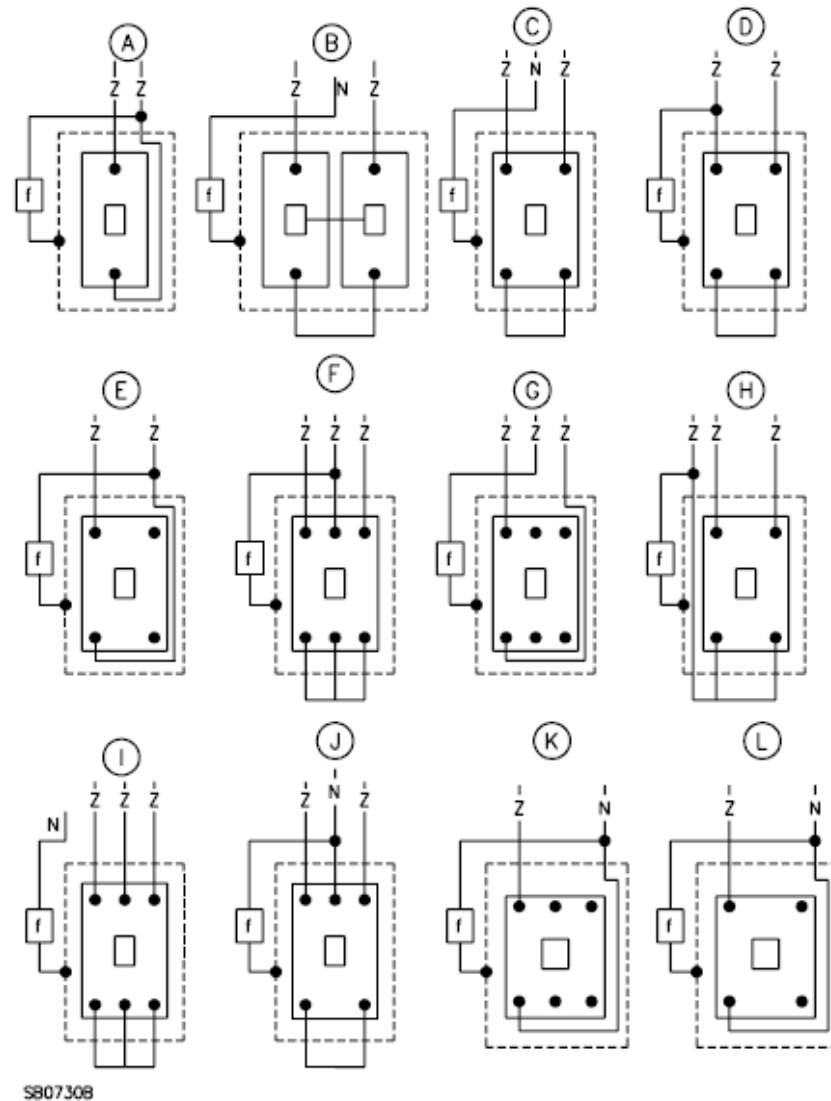
Because of the benefits and associated limitations of different types of grounding systems, testing of slash voltage-rated circuit breakers is different from the testing of straight voltage-rated circuit breakers. IEEE Std 142 [B5] discusses grounding considerations in detail. Slash voltage-rated circuit breakers take advantage of the fact that the power system neutral is fixed at ground potential. Table 4 indicates the various tests required of MCCBs and ICCBs as a function of the different numbers of poles of the circuit breaker and the different voltage ratings to be applied. More detail on the tests and the circuits they are performed in follows. Table 4 emphasizes the significant difference in testing required for circuit breakers to be rated with a straight voltage and those to be rated with a slash voltage. The informational note in NEC-2011 Section 240.83 is an excellent reminder of the significance of voltage rating.

Table 4—MCCB and ICCB interrupting ability operations^a

Poles	Frame rating	Circuit breaker ac voltage rating	Letters indicate diagram in Figure 6						Total number of operations
			Operations on each pole			Common operations			
			O	CO	O	O	CO	O	
1	All	120, 127, 208, 240, 277, 347, 480, 600	A	A	A	—	—	—	3
1	All	120/240 (tested in pairs)	—	—	—	B	B	B	3
2	All	240, 480, or 600	E	E	—	D	—	—	5
2	All	120/240	—	—	—	C	C	C	3
2	0 A-1200 A	208 Y/120, 480 Y/277, or 600 Y/347	L	L	—	C	—	—	5
2	All	1 Ø-3 Ø	E	E	—	H	—	—	5
3	0 A-1200 A	240, 480, 600	G	G	—	F	—	—	7
3	1200-up	240, 480, 600	G	G	—	F	—	—	7
3	All	120/240			—	J	J	J	3
3	0 A-1200 A	208 Y/120, 480 Y/277, 600 Y/347	K	K	—	I	—	—	7
3	1201-up	208 Y/120, 480 Y/277, 600 Y/347	K	K	—	I	—	—	7

^aFor the 125/250 V dc rating, the number of operations is the same as for the 120/240 V ac rating. For the 250 V dc rating, the number of operations is the same as for the 240 V ac rating.

Source: Table 7.1.7.1 of UL 489-2013



N - Neutral

Z - Limiting Impedance

F - 30 A "ground" Fuse - Enclosure

Source: Figure 7.1.7.1 of UL 489-2013

Figure 6—Interrupting ability test connection diagrams

4.13 Frequency rating and considerations

In North America, MCCBs, ICCBs, and LVPCBs are all basically rated for 60 Hz operation. Whenever they are capable of being applied at other frequencies, they are marked to indicate those other frequencies. For operation at any frequency not specifically indicated as applicable, the manufacturer should be consulted. Sometimes no changes are required in performance specifications. Sometimes it may simply be necessary to recalibrate a circuit-breaker trip unit for operation at the new frequency. Other times, for application at both lower and higher frequencies or for dc, a different trip unit may have to be used or the

circuit breaker may have to be de-rated. Occasionally, application of a given circuit breaker might have to be absolutely prohibited at another frequency or dc.

At higher frequencies, the phenomena of eddy currents and skin effect have significance. They affect circuit breaker components such as the primary current-carrying conductors or the iron cores of sensors and/or accessory devices. The extent of their effects on operation determines whether a given circuit breaker can be de-rated for use or cannot be used at all at higher frequency. At lower frequencies or dc, the method of current sensing may dictate whether a given circuit breaker can or cannot be used. Obviously, a circuit breaker using transformer action for current sensing in its trip unit cannot be used for dc applications. Air core sensors, also known as Rogowski coils, may also be affected by harmonics due to the fact that the sensor output signal is proportional to di/dt and hence can generate very high magnitude signals for high harmonics that exceed the capability of A/D converters or are limited by the slew rate of sensing circuitry.

4.14 Temperature considerations

Temperature affects circuit breaker operation in that below some limiting low temperature, mechanism operation will not be reliable due to possible freezing of condensation inside the circuit breaker, thickening of lubricants, and/or mechanical interference effects caused by changes in physical dimensions of components. Also, physical properties of materials may change. With extreme cold, some materials might tend toward brittleness. Temperature also affects circuit-breaker operation in that above some limiting high temperature, the mechanism operation will not be reliable because the physical or electrical strength limits of some materials may be reduced to marginal levels. Some materials can begin to melt, and the useful life of insulation will be seriously reduced. Each of these factors should be considered in detail by the circuit breaker designer and taken into account by the application engineer.

Total temperatures to which some insulating materials in LVPCBs may be subjected are listed in Table 5. These data are used by circuit breaker designers. Users of circuit breakers need only ensure that operation of the complete equipment will take place within the maximum and minimum limiting ambient temperatures.

Table 5—Limits of temperature rise in circuit breaker components

	Limit of temperature rise over air surrounding enclosure (°C)	Limit of total temperature (°C)
Class 90 insulation	50	90
Class 105 insulation	65	105
Class 130 insulation	90	130
Class 155 insulation	115	155
Class 180 insulation	140	180
Class 220 insulation	180	220
Circuit breaker contacts, conducting joints, and other parts (except the following)	85	125
Fuse terminals	See Footnote a	See Footnote a
Series coils with over class 220 insulation or bare	See Footnote a	See Footnote a
Terminal connections ^b	55	95

^aNo specified limit except not to damage adjacent parts.

^bTerminal connection temperatures are based on connections to bus in low-voltage metal-enclosed switchgear. If connections are made to cables, recognition must be given to possible thermal limitations of the cable insulation and appropriate measures must be taken.

Source: Table 3 of IEEE Std C37.13-2008

The standard operating ambient temperature range for MCCBs and ICCBs is -5°C to $+40^{\circ}\text{C}$ (23°F to 104°F). The standard operating ambient temperature range for LVPCBs is also -5°C to $+40^{\circ}\text{C}$ (23°F to 104°F), but IEEE Std C37.20.1-2002 permits the temperature of the cooling air surrounding the enclosure of low-voltage switchgear to be within the range of -30°C to $+40^{\circ}\text{C}$ (-22°F to $+104^{\circ}\text{F}$).

Since circuit breakers applied in temperatures outside their operating ranges may malfunction, the user should provide the operating conditions required to keep the temperature surrounding the assemblies and circuit breakers in their safe operating range. Sometimes it will mean that space heaters are required inside an enclosure to prevent condensation. Other times, special enclosures will be required not only for temperature control, but also possibly for environmental protection against contamination by particulate matter, liquids, or gas vapors. When extreme cold or hot ambient conditions are possible, the addition of separate heating or air cooling systems is necessary.

Sometimes forced ventilation alone can be sufficient to transfer enough heat to maintain an acceptable temperature; therefore, the use of increased forced air flow rather than the addition of air cooling equipment can be of economic advantage. When ventilating fans are used to establish current-carrying capability, it should be remembered that the current-carrying capability so obtained is now dependent on the operation of the fans, and fan performance may need monitoring.

Any necessary separate heating or air cooling equipment that is required for an application should be provided in the system design. It should be kept in mind that this equipment can be costly, can be heavy, and will occupy space. However, to obtain design life operation of switchgear and circuit breakers, ambient temperature limitations should be observed.

4.15 Enclosure considerations

All circuit breakers are fully rated for operation in free air at their listed maximum ambient temperature. All LVPCBs are applied in enclosures and all are fully rated for operation in their design enclosures with maximum design ambient temperature. LVPCBs are therefore said to be 100% rated. Some MCCBs are also 100% rated.

The requirements for 100% rating of MCCBs are given in paragraph 7.1.4.3 of UL 489-2013. Parts of some pertinent details concerning 100% rating are as follows:

- a) “A circuit breaker may be rated for continuous operation at 100% of its ampere rating if it is of a frame size rated 250 A or more or a multi-pole type of any ampere rating and rated higher than 250 V....”
- b) The candidate circuit breaker is tested for compliance with the 100% rating criteria in “the smallest enclosure with which the circuit breaker is likely to be used.”
- c) For compliance, “The temperature rises where connections are made to external bus bars, when bus bars are used; or on a wiring terminal at a point to which the insulation of a wire is brought up as in actual service when tested with insulated wire shall not exceed 60 °C (140 °F) if marked in accordance with 9.1.2.14....”

When the total terminal temperature in contact with insulation is 90 °C (194 °F), then a 90 °C (194 °F) rated conductor should be used. The minimum enclosure size for 100% rated application of MCCBs is indicated on the instruction sheet furnished with the circuit breaker and on the circuit breaker nameplate.

MCCBs that are not 100% rated are capable of operation in an enclosure at their rated maximum temperature at 80% of their free air current rating. Effective de-rating to 80% in application results from NEC rules stating that (1) the circuit must be wired for, and the rating of the overload device shall not be less than, the non-continuous load plus 125% of the continuous load and that the circuit must be wired for 125% of full-load ampacity, and (2) the circuit breaker must be applied according to the ampacity of the circuit. NEC Section 215.3, Exception #1 points out that the circuit-breaker rating should not be less than the non-continuous load plus 125% of the continuous load. Even with all continuous loads, this results in the circuit breaker effectively being applied at no more than 80% of conductor ampacity or 80% of its own free air current rating.

NEC rules account for the application of 100% rated MCCBs by stating in the exception to Section 210.19 that:

If the assembly, including the over current devices protecting the feeder(s), is listed for operation at 100% of its rating, the allowable ampacity of the feeder conductors shall be permitted to be not less than the sum of the continuous load plus the non-continuous load.

Because circuit breakers are tested and rated to account for these factors, engineers should be aware of all aspects of the application and installation environment and specify circuit breakers tested to satisfy all of them.

4.16 Cable, wire, and conductor considerations

The type, size, strand configuration, and compression of cable or wire conductor intended to be connected to a circuit breaker is an important application consideration and should satisfy at least two size requirements. First, the NEC requirement for load-carrying ability states that feeder conductors shall have sufficient ampacity to supply the load served. Rules of the NEC should be followed to establish the minimum acceptable wire size for the circuit. Second, if the 75 °C rated wire size of Table 6 is not used for the circuit, then it should be used in the last 4 ft of the circuit to satisfy the circuit breaker requirements. To satisfy voltage drop requirements, the circuit conductors might be sized a little larger, but they must always be able to fit into the circuit-breaker connectors. They can never be sized a little smaller. Circuit-breaker conductors also serve as conductive heat sinks for the circuit breaker. It is for the heat sinking requirement that the conductors should have a minimum cross-sectional conductor area equal to the cross-sectional conductor area of the 75 °C (167 °F) rated wire specified in Table 6 for a given terminal current. The wire insulation temperature rating should, of course, match the application.

Even though MCCBs are designed to operate in a 40 °C (104 °F) maximum ambient, the operating ambient temperature is not always 40 °C (104 °F). UL 489-2013 allows for the surface of conductor insulation to rise 35 °C (rise 63 °F) above the normal ambient, which might be 25 °C (77 °F), a common normal room temperature, giving a total temperature of 60 °C (140 °F). With the maximum permissible rise of 50 °C (90 °F rise) on the terminals during temperature test, and again with a 25 °C (77 °F) ambient, the total temperature would be 75 °C (167 °F). These numbers are the basis for the 60 °C or 75 °C or 60 °C/75 °C conductor insulation ratings specified for the conductors used with MCCBs rated 125 A or less. For MCCBs rated greater than 125 A, the 75 °C conductor insulation rating is normal (called rated wire). When an MCCB is 100% rated, the maximum permissible terminal temperature rise during test is 65 °C (117 °F). When added to a 25 °C (77 °F) ambient, the total is 90 °C (194 °F). UL 489 rules require that if the terminal temperature rise during 100% rating test exceeds 50 °C (90 °F rise), then the circuit breaker should be marked "For use with 90 °C (194 °F) wire and the wire size." The nameplate, in that case, would be marked accordingly.

Designers may want to use smaller, higher temperature rated wire. The application engineer should remember that when 90 °C (194 °F) insulated conductor is specified for a given ampacity, the cross-sectional area of the metal conductor inside the 90 °C (194 °F) rated insulation will generally be smaller than the cross-sectional area of the normal 75 °C (167 °F) rated conductor that was used to proof test the circuit breakers. If it is smaller, it will not be able to provide sufficient heat sinking capacity for normal circuit-breaker performance and should not be used. Therefore, conductors connected to circuit breakers should always have a cross-sectional area equal to at least that of the 75 °C (167 °F) rated conductor specified for the application.

A properly sized conductor, in addition to having sufficient ampacity, will also be stranded to satisfy the requirements of the circuit breaker terminals or connectors. It will have a sufficient cross section to adequately heat sink the circuit breaker, it will be insulated for the temperature conditions existing in all spaces through which it will pass, and it will be able to withstand fault-interrupting forces and temperature

changes without experiencing inordinate damage. Circuit breakers are tested with a rated conductor to prove these capabilities. Therefore, the rated wire size is sufficient for normal operation.

Many operating problems with circuit breakers start at the terminals. Therefore, all connectors used to connect conductors to circuit breakers at both the line side and the load side should be properly matched for size, material, and temperature rating, and it should always be confirmed that they fit the circuit breaker terminals, that they are clean, properly coated with anti-oxidants when required, and that they are torqued properly when installed. The connectors should be able to firmly hold the conductors in place against the forces that are imposed on them during short circuits. Standard interruption tests prove they can. It may be necessary to rope-tie conductors into place in some cases. When this approach is necessary, instruction sheets describe how it is to be done. The number of strands making up stranded conductor is an important factor in how well connectors can hold conductors against magnetic forces. See Table 8 for a listing of normal conductor stranding to be used for circuit-breaker wiring, and see the notes below that table. The NEC requires stranding for conductors of size 8 AWG and larger.

Note that very flexible, finely stranded conductor, sometimes called welding cable, should not be used unless the connector is designed for it because the fine stranding is difficult or impossible to constrain under some standard terminal clamps. Sometimes the fine strands squeeze out from under the clamp, gradually loosening the connection. At the other extreme, conductors with fewer strands, but not compressed, can sometimes be tightly held with the first tightening, but as the conductor goes through heat expansion and contraction cycles or if the conductor is forced to move physically, the strands can rearrange themselves under the clamp, again resulting in a loose connection. The higher resistance of loose conductors generates excess heat with rated current flow. The connectors specified by the manufacturer of the circuit breaker should be used because they are the ones used in proof testing. For more information on connectors and conductors, the interested reader is referred to the UL 486 series of standards on connectors ([B22] through [B25]).

These factors affect circuit-breaker operating temperature and are as important as ampacity. They are taken into account in the design and validation testing of circuit breakers.

UL 489-2013 requires in paragraph 9.1.2.9 that:

A circuit breaker, circuit-breaker frame, or interchangeable trip unit rated 100 A or less or that is not marked for use with wire sizes of 1/0 or larger, shall be marked as being suitable for 60 °C (140 °F), 75 °C (167 °F) only, or 60/75 °C (140/167 °F) wire, except that if the circuit-breaker frame is so marked, the interchangeable trip unit need not be marked.

The UL listed wire size and type should be used. Table 6 lists rated wire sizes for the various terminal currents or circuit currents. For proper circuit-breaker application, these wire sizes are a necessity. They are the sizes used in proof testing of circuit breaker designs.

Table 6—Terminal current and conductor size

Terminal current in Amperes ^a	Copper conductor			Aluminum or copper-clad aluminum conductor		
	Number of conductors	Size AWG or kcmil		Number of conductors	Size AWG or kcmil	
		60 °C	60 °C		60 °C	75 °C
15 or less	1	14	14	1	12	12
20	1	12	12	1	10	10
25	1	10	10	1	10	10
30	1	10	10	1	8	8
40	1	8	8	1	6	8
50	1	6	8	1	4	6
60	1	4	6	1	3	4
70	1	4	4	1	2	3
80	1	3	4	1	1	2
90	1	2	3	1		2
100	1	1	3	1		1
110	1		2	1		1/0
125	1		1	1		2/0
150	1		1/0	1		3/0
175	1		2/0	1		4/0
200	1		3/0	1		250
225	1		4/0	1		300
250	1		250	1		350
275	1		300	1		500
300	1		350	1		500
325	1		400	2		4/0
350	1		500	2		4/0
400	2		3/0	2		250
	1		500	1		750
450	2		4/0	2		300
500	2		250	2		350
550	2		300	2		500
600	2		350	2		500
700	2		500	3		350
800	3		300	3		400
1000	3		400	4		350
				3		600
1200	4		350	4		500
	3		600			
1400	4		500	5		500
1600	5		400	5		600
	4		600			
2000	6		400	6		600
	5		600			
2500	8		400	8		600
	7		500	7		750
	6		600	9		500
3000	9		400	10		500
	8		500	9		600
	7		600	8		750
4000	12		400	13		500
	11		500	12		600
	10		600	11		750

Table 6—Terminal current and conductor size, continued

5000 ^b	15		400	16		500
	13		500	15		600
	12		600	13		750
6000 ^b	18		400	19		500
	16		500	18		600
	15		600	16		750

^aFor terminal current other than indicated, the next higher rating is to be used; for example, in rated 35 A, enter at 40 A.

^bCircuit breakers rated at more than 4000 A are to be considered as being bus- or cable-connected unless indicated otherwise in marking.

mm ²	2.1	3.3	5.3	8.4	13.3	21.1	26.7	33.6	42.4	53.5
AWG	14	12	10	8	6	4	3	2	1	1/0
mm ²	67.4	85.0	107.2	127	152	177	203	253	304	380
AWG or kcmil	2/0	3/0	4/0	250	300	350	400	500	600	750

Source: Table 6.1.4.2.1 of UL 489-2013

Maintenance personnel should remember that when a high level fault occurs, the circuit breaker and the conductors should be inspected for damage, and all damaged components should be repaired or replaced before reclosing the circuit breaker that experienced the fault.

In summary, all conductors intended to be connected to circuit breakers should start with the size of the conductor used to establish their rating per 9.1.2.9 of UL 489-2013. They should:

- a) Be rated to carry the required maximum full-load current.
- b) Be large enough to limit voltage drop to an acceptable application level.
- c) Be large enough to withstand circuit-breaker fault interruption let-through current.
- d) Be small enough to fit into the circuit breaker connectors where they can be held tightly in place during a fault.
- e) Be insulated for the rated system voltage.
- f) Be of the correct stranding and construction to permit proper torquing.
- g) Have an insulation temperature rating and composition suitable for the total application.
- h) Be coated with the proper anti-oxidant whenever required, i.e., aluminum conductor terminations.

4.17 De-rating for ambient temperature

MCCBs, ICCBs, and LVPCBs all should be de-rated for their current-carrying capacity when operated in ambient temperatures above their rated maximum. The manufacturer of the circuit breaker should be consulted for the applicable de-rating information for a particular unit. There are formulas for calculation of current de-rating that are based on simplifying assumptions and empirical factors. These formulas should be used with discretion.

For LVPCBs, equation 8.4.1 of IEEE Std C37.20.1-2002 can be used to determine a continuous-load current capability based on actual ambient temperature. See equation (1):

$$I_a = I_r \left[\frac{\theta_{max} - \theta_a}{\theta_r} \right]^{1/20} \quad (1)$$

where

- I_a is the allowable de-rated current (A) (never to be more than two times I_r)
- I_r is the rated continuous current (A)
- θ_{max} is the allowable hottest spot total temperature = $(\theta_r + 40^\circ\text{C})$
- θ_a is the actual ambient temperature ($^\circ\text{C}$) expected
- θ_r is the allowable hottest spot temperature rise ($^\circ\text{C}$) at rated current

The specifying engineer should always refer to the circuit breaker manufacturer for the best possible guidance in de-rating.

For MCCBs using bimetallic overload trips, it is best to consult the manufacturer's temperature de-rating tables for the particular circuit breaker of interest because different bimetallic pairs operate at different temperatures. Obviously, trip mechanism designs and calibration methods can vary. However, the following general guidelines can be used to make rough estimates of expected thermal performance capability. Assuming temperature rise proportional to current squared, and taking the ratio of a known condition to an unknown condition, de-rated current can be solved as follows:

$$I_2 = I_1 \sqrt{(T_2 - A_2)/(T_1 - A_1)} \quad (2)$$

where

- T_1 is the circuit breaker bimetallic element temperature, or the total terminal temperature for electronically tripped circuit breakers ($^\circ\text{C}$) at rated current of I_1 amperes with rated ambient temperature A_1 $^\circ\text{C}$
- T_2 is assumed to remain approximately the same as T_1 , not being too much affected by the practical difference in ambient temperatures
- A_2 is the new ambient temperature ($^\circ\text{C}$)
- I_2 is an estimate of the current the circuit breaker is likely to be able to carry in an ambient temperature of A_2 $^\circ\text{C}$

Equation (2) does not take into account any built-in compensation and as suggested can even be used to estimate thermal de-rating of electronically-tripped circuit breakers by using the total terminal temperature for T_1 and T_2 . For example, assuming a 50°C (90°F) terminal rise over a 40°C (104°F) ambient for a total temperature of 90°C (194°F) gives $T_1 = T_2 = 90^\circ\text{C}$ (194°F) for rough estimating. The engineer should know the internal temperatures more accurately to reproduce manufacturer's de-rating data, but in the absence of manufacturer's data, Equation (2) gives some guidance.

It should be remembered that the properties of the materials used in the construction of circuit breaker components determine the maximum limiting temperature allowable for any given circuit breaker, and they therefore determine the amount of de-rating necessary for any given over-temperature condition. Temperature limitations on current transformers, for example, can be more restrictive than limitations on the circuit breaker. The properties of materials used in different circuit breakers can be different even when circuit breakers are similar in rating.

4.18 Circuit breaker humidity limitations

The effect of humidity on any circuit breaker is a function of temperature. UL 489 sets an operating limit on relative humidity in clean air at a level of not more than 50% at a maximum temperature of 40°C . However, it recognizes that a higher level of as much as 90% relative humidity at a lower temperature of 20°C could be satisfactory as long as consideration is given to the fact that moderate condensation is possible.

The detrimental effects of condensation are multiplied when water-soluble contaminants can also be present inside an enclosure. NEMA standardized enclosure types are available for various application conditions. When condensation is known to be possible in the application area, the circuit breaker enclosures should at least be equipped with space heaters in the internal space intended to prevent internal condensation by heating the air a small amount and allowing gravity to keep the internal air in motion.

4.19 Circuit breaker altitude limitations

The altitude of an installation is important because, as altitude increases, atmospheric pressure and air density decrease. The reduced insulation and heat transfer properties of less dense air require that circuit breakers be de-rated for voltage withstand and current-carrying capacity as a function of altitude, assuming the temperature remains constant. But temperature typically goes down with an increase in altitude, so current de-rating tends to be compensated for, to some degree, naturally. However, voltage withstand capability is essentially unaffected by lower temperature, so a voltage correction factor for altitude is applied.

MCCBs and ICCBs should be de-rated for voltage, current-carrying capacity, and sometimes interrupting capacity when applied at or above 1830 m (6000 ft) above mean sea level.

LVPCBs should be de-rated when applied at or above 2000 m (6600 ft) above mean sea level. Table 7, taken from IEEE Std C37.13-2008, lists the specific altitude rating correction factors for LVPCBs. The manufacturers of MCCBs and ICCBs should be consulted for specific information on de-rating for altitude.

Table 7—Altitude rating correction factors

Altitude		Rated continuous current	Rated voltage
(ft)	(m)		
6600 and below	2000 and below	1.00	1.00
8500	2600	0.99	0.95
13 000	3900	0.96	0.80

NOTE—Values for intermediate altitudes may be derived by linear interpolation.

Source: Table 5 of IEEE Std C37.13-2008

There are few test sites in the world where actual altitude testing can be performed, and simulated altitude test facilities are few and far between. Instead, test voltage levels adjusted for the normal altitude conditions of the manufacturing site are used to test insulation integrity, and if necessary, rules based on theory and confirmed by experience are applied to answer practical interruption performance questions. The theoretical guidelines established for this purpose have proven to be quite satisfactory in application.

4.20 Circuit breaker ampere rating considerations

Circuit breaker current rating can vary significantly, and an individual circuit breaker's rating can be impacted by external factors. The best example of the latter is thermal-magnetic molded case circuit breakers and conductor sizes. Molded case circuit breakers from 15 A to 6000 A are mentioned in UL 489 and are commonly available. Low-voltage power circuit breakers from 600 A to 6000 A are mentioned in IEEE Std C37.16 and are commonly available. See 4.16 for further discussion.

The thermal characteristics of a circuit breaker are affected by the temperature of the environment, the enclosure, and the conductor connections and size or type of the conductors. A molded case thermal-magnetic circuit breaker uses the heat created by a metallic strip within the circuit breaker to sense the long-time tripping characteristics, what is usually referred to as the long-time curve. The circuit breaker forms a thermal system with the connected conductors. The circuit breaker creates a certain amount of heat with the current flowing through it, as do the terminals and connected conductors. If the conductors are too

small, then the conductors create too much heat and do not absorb the heat created by the circuit breaker. Excess heat can then cause the circuit breaker to trip faster (become over sensitive). If the conductors are too large, then they can act as a heat sink for the circuit breaker mechanism and slow (or desensitize) the tripping characteristics. Hence, molded case circuit breakers are tested with specific conductor sizes and must be used with the conductors identified by the manufacturer as appropriate for the device. In the case of molded case thermal magnetic circuit breakers, the conductors can be too large or too small.

Circuit breakers are also defined to be used in enclosures with certain minimum sizes. The main reason is to provide enough enclosure size, or surface area, to allow the device to release heat produced by current. The use, or type of enclosure, can also affect if the circuit breaker may be 100% or 80% rated. When installing circuit breakers within enclosures, it is important to follow the manufacturer's guidelines and not use an enclosure that is too small. Manufacturers normally provide UL listed enclosures for their circuit breakers that are sized appropriately. If installing a circuit breaker in a third party enclosure, care must be taken to ensure it is of sufficient size to accommodate the circuit breaker and cables, as well as provide enough surface area and volume to provide adequate cooling. Instructions provided by the manufacturer, or the manufacturer of the circuit breaker, should be consulted.

Circuit breakers are also listed for use in an environment within a specific temperature range. Molded case circuit breakers and low-voltage power circuit breakers are listed for use within a 40 °C environment. Enclosures are usually listed for use in a 25 °C environment. There is an implicit assumption that the temperature inside the enclosure may be up to 15 degrees higher than the temperature outside the enclosure. Manufacturers may provide devices able to operate at slightly higher temperatures and will also provide temperature de-rating methodology for devices that must operate in environments with higher temperature (see 4.17). Thermal-magnetic circuit breakers that operate in higher than normal temperature environments will experience a shift in their long-time curve to the left. If the circuit breaker is operating in a particularly cool environment, the long-time curve will shift to the right. Manufacturers will normally identify these shifts in their published curves.

Circuit breakers with electronic trips could have their current rating determined by several factors. The frame and conductor sizes, or hardware provided for releasing heat within the circuit breaker, are the final limit on a device's current rating. However, the circuit breakers can also be limited by the sensor size or by the characteristics of the electronic trip. A particular physical size of circuit breaker may be offered by a manufacturer with several different sensor sizes. The sensor size will limit the maximum current rating for that device and may be marketed as a different frame size (in amperes) even though to a casual observer it may appear similar to another circuit breaker with a different frame size (in amperes). Many trip units also use interchangeable field installable rating plugs to lower the effective current rating of a circuit breaker. The long-time current pickup range is affected by the rating plug installed in the trip unit, as may be the instantaneous pickup range. In some cases, the instantaneous may remain a function of the sensor and be unaffected by rating-plug selection. Electronic trip units and rating-plugs are commonly available in molded case circuit breakers as well as low-voltage power circuit breakers.

4.21 National Electrical Code considerations

Article 240 of the NEC, entitled "Overcurrent Protection," gives guidance to the application engineer and the circuit breaker designer. Section 240.4 of the NEC states that, "Conductors, other than flexible cords and fixture wires, shall be protected against overcurrent in accordance with their ampacities as specified in Section 310.15...." Circuit breaker tests with wire and bus prove that circuit breakers can protect conductors. Standard wire ampacities are therefore of interest to the systems engineer and the circuit breaker designer when deciding on ampere ratings. Since the circuit breaker should protect the conductors, the choice of circuit breaker and conductor are related. When circuit breakers have trip units that fit into a single large frame, the following NEC consideration can be important to the circuit breaker and trip unit choice.

The ampere rating of a circuit breaker is described in NEC Section 240.6, which lists the standard ampere ratings to be considered and further states in part (B), “The rating of adjustable-trip circuit breakers having external means for adjusting the current setting (long-time pickup setting), not meeting the requirements of 240.6(C), shall be the maximum setting possible.” This ruling could affect project economics were it not for part (C) to the rule. Without part (C), the rule would require wiring to be for the maximum circuit breaker trip level instead of for the maximum load current.

The exception to the rule, Part (C), states that “A circuit breaker(s) that has restricted access to the adjusting means shall be permitted to have an ampere rating(s) that is equal to the adjusted current setting (long-time pickup setting). Restricted access shall be defined as located behind one of the following:

- 1) Removable and sealable covers over the adjusting means
- 2) Bolted equipment enclosure doors
- 3) Locked doors accessible only to qualified personnel”

This exception gives the circuit breaker design engineer and the power system design engineer some latitude to affect power system economics. A simple feature like the provision of a sealable cover for the circuit breaker trip unit will allow a larger frame circuit breaker to be applied on a smaller ampacity circuit with the correct overload ampere trip setting. This feature makes it possible to keep the conductor size proportional to the circuit ampacity, thereby reducing the cost of the circuit conductors required, and it makes possible the realization of economic benefits in commonality in the type of circuit breakers used and in the stocking of spares. Circuit breaker testing with different trip units makes this possible.

NEC rules apply to all types of circuit breakers and are consistent with the primary purpose of these rules and the exception (i.e., to protect the wire or bus and to do so safely); all circuit breakers are tested with rated wire or bus. This safety code provision recognizes the efficacy of circuit breaker test methods and offers the benefits of this demonstrated circuit breaker capability to users.

4.22 Preferred current ratings

The frame sizes for MCCBs and ICCBs are listed in Table 2. Frame sizes for LVPCBs are listed in Table 8 and Table 9. It is from these lists that circuit breaker frame sizes are chosen. Table 10 indicates the preferred ratings for LVPCBs that are integrally fused and use instantaneous direct-acting phase trip elements.

Table 8—Ranges of preferred short-circuit ratings for low-voltage ac power circuit breakers and short-circuit current ratings for low-voltage ac power circuit breakers without instantaneous direct-acting phase trip elements (short-time-delay elements or remote relay)

Line no.	Circuit-breaker frame size amperes	Short-circuit current rating (kA)/Short-time current rating (kA) ^a	
		Minimum	Maximum
	Col. 1	Col. 2	Col. 3
1	600 ^b	22	22
2	800	22	85
3	1600	42	85
4	2000	42	85
5	3000 ^b	65	65
6	3200	65	100
7	4000	85	100
8	5000	85	100
9	6000	85	100

^aThe preferred rated short-circuit current shall be one of the following values: 22 kA, 30 kA, 42 kA, 50 kA, 65 kA, 85 kA, or 100 kA.

^bPreferred ratings for 600 A and 3000 A frame sizes are provided for historical reference.

Source: Table 2 of IEEE Std C37.16-2009

Table 11 lists standard ampere ratings taken from NEC Section 240.6.

Circuit breaker manufacturers design trip units for the various preferred ampere levels spanned by different frame sizes. All circuit breakers are tested with the various trip units installed to demonstrate both their time-current tripping characteristics and the circuit breaker's interrupting capability with that trip unit installed. The ability of a circuit breaker to protect rated cable or bus is demonstrated simultaneously because the test circuit is made up of a specified size bus or wire of rated wire size. See the individual manufacturer's literature for available trip unit ampere ratings.

Table 12 lists the preferred trip-device current ratings or settings for LVPCBs.

Table 9—Ranges of preferred short-circuit ratings for low-voltage ac power circuit breakers with instantaneous direct-acting phase trip elements

Line no.	Circuit-breaker frame size amperes	Short-time current rating (kA) ^a			
		Minimum	Maximum at 254 V	Minimum at 508 V	Maximum at 635 V
	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
1	600 ^b	22	42	30	22
2	800	22	200	200	130
3	1600	42	200	200	130
4	2000	42	200	200	130
5	3000 ^b	65	85	65	65
6	3200	65	200	200	130
7	4000	85	200	200	130
8	5000	85	200	200	130
9	6000	85	200	200	130

^aThe preferred rated short-circuit current shall be one of the following values: 22 kA, 30 kA, 42 kA, 50 kA, 65 kA, 85 kA, 100 kA, 130 kA, 150 kA, or 200 kA.

^bPreferred ratings for 600 A and 3000 A frame sizes are provided for historical reference.

Source: Table 1 of IEEE Std C37.16-2009

Table 10—Preferred fuse ratings for integrally and non-integrally fused LVPCBs

300	1200	3000
600	1600	4000
800	2000	5000
1000	2500	6000

The rated short-circuit current is 200 kA.

Fused circuit breakers do not have a short-time current rating.

^aThis rating is the rms symmetrical value for single-phase (2-pole) circuit breakers and three-phase average rms symmetrical value of three-phase (3-pole) circuit breakers. On systems where the voltage across a single pole exceeds 58% of the rated maximum voltage, the short-circuit rating shall be 87% of the three phase value.

Source: 3.6.2 of IEEE Std C37.16-2009

Table 11—Standard ampere ratings for inverse-time circuit breakers

15	70	225	1000
20	80	250	1200
25	90	300	1600
30	100	350	2000
35	110	400	2500
40	125	500	3000
45	150	600	4000
50	175	700	5000
60	200	800	6000

Source: Section 240.6 of the NEC-2011

Table 12 —Preferred trip device current ratings or settings for LVPCBs (in amperes)^{a,b}

AC power circuit breakers		General purpose dc power circuit breakers
Electronic trip systems ^a	Electromechanical trip systems ^b	Electromechanical trip systems ^c
100	40	40
150	50	50
200	70	70
400	90	90
600	100	100
800	125	125
1200	150	150
1600	175	175
2000	200	200
3000	225	225
3200	300	300
4000	350	350
5000	400	400
6000	500	500
	600	600
	800	800
	1000	1000
	1200	1200
	1600	1600
	2000	2000
	2500	2500
	3000	3000
	3200	3200
	4000	4000
	5000	5000
		6000

^aThe continuous current rating for the trip system must be less than or equal to the frame rating of the circuit breaker. The continuous-current-carrying capability of some circuit breaker-trip-device combinations may be higher than the trip-device current rating (IEEE Std C37.13).

^bThe continuous current rating for the trip system must be less than or equal to the frame rating of the circuit breaker. The continuous-current-carrying capability of some circuit breaker-trip-device combinations may be higher than the trip-device current rating (IEEE Std C37.13).

^cThe continuous-current-carrying capability of some circuit breaker-trip-device combinations may be higher than the trip-device current rating (IEEE Std C37.14).

Source: 5.3 of IEEE Std C37.16-2009

4.23 Load effects

Continuous current ratings required of circuit breakers can be affected by the characteristics of the loads being served. Harmonics are generated when a load draws a non-linear current from a sinusoidal voltage. Harmonics in nonlinear loads and high, short-time inrush loads like those of tungsten filament lamps and premium-efficiency motors and transformers at startup can affect the circuit breaker contacts and can be interpreted by trip circuit logic as overloads or faults. These load effects are applicable to all circuit breakers due to their thermal effect on the circuit breaker and in their interpretation by protective elements as faults or overloads. Manufacturers generally provide guidelines for application on high harmonic circuits and circuits that may exhibit extreme transient loading. The guidelines may include de-rating of the current carrying capacity and guidance on how to account for the effect on protective logic. Tungsten filament lamp rating, heating and air conditioning rating (HACR), and high-intensity-discharge (HID) rating, for example, are specially tested load ratings. NEC rule changes allow for higher instantaneous trip levels for premium-efficiency motors.

4.24 The effect of nonlinear loads on circuit breakers

Modern drives and controls using electronic power-switching devices generate harmonic currents that propagate throughout the power system as a function of the impedances of the various paths. Although capacitor banks do not generate harmonic currents, they are low-impedance sinks for power system harmonic currents. Regardless of where the harmonic currents originate, if they flow into a capacitor bank, they do so by flowing through the associated circuit breaker or fuse controlling the capacitor bank. To provide adequate thermal protection under these conditions, circuit breaker trip units must be able to respond accurately to the load current regardless of harmonic content. Bimetallic thermal elements, generally, respond to rms directly through the heat produced in them, and newer electronic trip units have been designed with sampling and processing algorithms to provide correct rms current sensing in the presence of harmonics up to some manufacturer-defined harmonic level.

For more information on the subject of harmonics, the reader is referred to IEEE Std 519 [B10]. For more information on capacitor bank applications in particular, refer to NEMA CP 1 [B16]. Not all protective algorithms operate of rms current values, particularly instantaneous elements that may look at instantaneous values, di/dt , peak values, energy, or other combination of load-related parameters.

Resistance welding applications can also generate harmonics. Rapid rises in current followed by sharp cutoffs constitute non-sinusoidal current waveform during a welding operation. The nominal load level is the average of the rms peaks and valleys over a period of time. The duty cycle of a process, even with sinusoidal waveform, can also affect the required circuit breaker rating. Refer to Article 630 III of the NEC for discussion about resistance welding applications. Load nonlinearity can affect circuit breakers through trip-unit sensitivity to current peaks as well as through circuit breaker component heating. Test procedures do not currently include provisions to account for nonlinear load effects, but as such loads continue to proliferate, the effects of nonlinearity can be expected to become more noticeable on the power system, and ultimately, engineers can expect to be required to take them into account in testing procedures.

Many modern microprocessor-based signal processing trip units include a thermal memory algorithm based on preceding current level history so they can take into account the heating effect of that current flow as do bimetallic elements and real utilization devices. With these capabilities, they can provide protection for power circuits feeding nonlinear loads.

At this time, there is no commonly accepted specification of a test waveform that microprocessor trip units should be able to sample and accurately quantify. However, circuit breaker manufacturers have done extensive development testing to provide assurance that their digital sampling algorithms will work to the degree that they specify in their technical literature.

4.25 The effect of high inrush loads

If loads are cycled on and off or up and down in level, or if motor plugging¹ is involved in an application, the current rating and type of circuit breaker trip unit should be chosen carefully. It may be necessary to consult the manufacturer of any type of circuit breaker for guidance under these conditions. Large inrush current with potentially high offset peaks and longer duration high continuous current flows accompanies these operations, making them unlike normal motor starting duty, and these operations may occur more frequently in a process. The response of the circuit breaker trip unit to these higher currents and offsets and their heating effect on the circuit breaker should be evaluated. Such effects are considered in circuit breaker overload testing.

¹ Motor plugging is the process of reversing the polarity of dc motors or reversing the phase-rotation of ac motors and applying power to rapidly stop or change the speed and/or direction of the motor's coupled load.

4.26 Overload testing of circuit breakers

MCCBs, ICCBs, and LVPCBs are tested to interrupt overload current at 600% of rated current a given number of times. ICCB and MCCB minimum overload test current is 150 A. See Table 13 and Table 14. Table 15 and Table 16 summarize the overload testing parameters and indicate data for comparison.

The definitions of overcurrent and overload in Article 100 of the NEC can be helpful in understanding short-circuit interrupting and overload testing. It is important not to confuse these terms (see 3.1.35 and 3.1.36).

Table 13—Overload test operations for MCCBs and ICCBs^a

Frame size, amperes	Number of operations			Number of cycles of operation per minute
	Circuit breakers		Switches	
	Close and open manually ^{b,c,d}	Close manually, open automatically		
100 or less	35	15	50	6
101 – 150	50 ^e	— ^e	50	5
151 – 225	50	—	50	5
226 – 1600	50	—	50	1 ^f
1601 – 2500	25	—	25	1 ^f
2501 – 6000	28	—	28	1 ^g

^aThe operation may be performed by a machine simulating manual operation.

^bIf the test sample trips during manual operation, it is still considered a manual operation.

^cAt the option of the manufacturer, the adjustable instantaneous response of a circuit breaker rated 400 A or more may be adjusted to less than the maximum position.

^dThe minimum closed time shall be one cycle, unless the sample trips.

^eIn the case of a multi-pole breaker without a common trip, and rated at more than 100 A, 35 cycles of operation shall be made manually and 15 automatically as specified in 7.1.3.14 of UL 489-2009.

^fOperation may be conducted in groups of five with 15 min maximum between groups.

^gThree operations at 600% of rating at the rate of one cycle per minute, followed by 25 operations at 200% of rating at the rate of 1 cycle per minute (may be conducted in groups of five with 15 min maximum between groups).

Source: Table 7.1.3.1 of UL 489-2013

**Table 14—Overload switching requirements for low-voltage ac power circuit breakers
(see ANSI C37.50)**

Line no.	Circuit breaker frame size amperes	Number of make-break operations
	Col 1	Col 2
1	600	50
2	800	50
3	1600	38
4	2000	38
5	3000	*
6	3200	*
7	4000	*
8	5000	*

*Not applicable.

Source: Table 3 of IEEE Std C37.16-2009

Table 15—Circuit-breaker overload performance test comparison

Frame size (amperes)	Number of operations ^{a, k}					
	Number of cycles of operation per minute		Close (make) and open (break) manually		Close (make) manually and open (break) automatically	
	UL 489-2013 ^j	ANSI C37.50-2012	UL 489-2013 ^{b, c, d}	ANSI C37.50-2012	UL 489-2013	ANSI C37.50-2012
100 or less	6	—	35	—	15	—
150	5	—	50 ^e	—	^e	—
225	5	—	50	—	—	—
600	1 ^f	1 ⁱ	50	50	—	50
800	1 ^f	1 ⁱ	50	50	—	50
1200	1 ^f	—	50	—	—	—
1600	1 ^f	1 ⁱ	25	38	—	38
2000	1 ^f	1 ⁱ	25	38	—	38
2500	1 ^f	—	25	^h	—	^h
3000	1 ^g	1 ⁱ	28 ^g	^h	—	^h
3200	1 ^g	1 ⁱ	28 ^g	^h	—	^h
4000	1 ^g	1 ⁱ	28 ^g	^h	—	^h
5000	1 ^g	1 ⁱ	28 ^g	^h	—	^h
6000	1 ^g	1 ⁱ	28 ^g	^h	—	^h

^aOverload switching test for circuit breakers is conducted at 600% of its rated current for both closing (making) and opening (breaking) operations.

^bIf the test sample trips during manual operation, it is still considered a manual operation.

^cAt the option of the manufacturer, the adjustable instantaneous response of a circuit breaker rated 400 A or more may be adjusted to less than the maximum position.

^dThe minimum closed time shall be one cycle, unless the sample trips.

^eIn the case of a multi-pole breaker without a common trip, and rated at more than 100 A, 35 cycles of operation shall be made manually and 15 automatically as specified in 7.1.3.14.

^fOperation may be conducted in groups of five, with 15 min maximum between groups.

^gThree operations at 600% of rating at the rate of one cycle per minute, followed by 25 operations at 200% of rating at the rate of one cycle per minute (may be conducted in groups of five with 15 minutes maximum between groups).

^hNot applicable—circuit breaker frame sizes greater than 2000 A are not typically applied in feeder applications, in particular, applications such as motor starters.

ⁱGroups of operations may be separated by intervals of up to 15 min maximum.

^jThe operations may be performed by a machine simulating manual operation (from note a, Table 7.1.3.1 of UL 489-2013).

^kThe operations may be performed by a machine simulating manual operation.

Source: Table 7.1.3.1 of UL 489-2013 and IEEE Std C37.16-2009

Table 16—Overload test parameters

Parameter	UL 489-2013	ANSI C37.50-2012
Enclosure	Smallest individual	Min dimension test enclosure
Current (ac) (dc)	6 × rated 6 × rated	6 × rated
Voltage	100%-105% rated	100%-105% rated max (254 V, 508 V, or 635 V)
Power factor (ac)	0.45-0.50	0.5
Time constant (dc)	3 ms min	Not applicable
Frequency	48 Hz-62 Hz	48 Hz-72 Hz
Ambient	Not defined	Not defined
Ground fuse	30 A	30 A fuse or 10 AWG (copper)

Source: UL 489-2013 and ANSI C37.50-2012

4.27 Forced-air cooling of LVPCBs

In the case of LVPCBs, forced-air cooling may be used as an option to obtain additional continuous current-carrying capacity. Although a system might be intentionally designed to use forced-air cooling, it is most likely that this approach would be decided on as a backup contingency only because the ability of the circuit breakers to carry the required load current in this mode depends on the operation of the air-moving fans. The reliability of the fans becomes a most important factor in the overall reliability of the circuit breaker system.

Obviously, testing is necessary to prove the current-carrying capability of a circuit breaker with forced-air cooling because modeling of air flow and heat transfer inside circuit breakers and enclosures is a difficult process at best and unexpected failure of a system can have unacceptable consequences. If forced-air cooling seems to be required or of advantage, the engineer should see 9.1.3.2 of IEEE Std C37.13-2008 for additional discussion of the factors to be considered and discuss the matter further with the manufacturer.

4.28 Short-circuit interrupting rating

Short-circuit interrupting rating addresses the ability of a circuit breaker to interrupt the actual flow of fault current in a circuit having a given prospective fault-current level and to protect the conductors connected to the circuit breaker. The short-circuit interrupting ratings for low-voltage ac power circuit breakers are shown in Table 8 and Table 9. The circuit breaker interrupting rating is given on a symmetrical rms ampere basis. The symmetrical short-circuit interrupting rating of the circuit breaker takes into account the initial current offset due to the circuit X/R ratio. The value of the standard X/R ratio is used in the test circuit, and its effect is therefore included in the interrupting rating. For unfused LVPCBs, the implicit value of X/R is 6.6 (0.15 power factor), whereas for fused LVPCBs, it is 5.0 (0.20 power factor). For MCCBs and ICCBs, the implicit value of X/R used in the test circuit varies with the short-circuit current rating of the circuit breaker, having a maximum value of 4.9 (0.20 power factor). See IEEE Std 399™ (*IEEE Brown Book™*) [B8] for a more detailed discussion of short-circuit studies.

One benefit of rating circuit breakers on a symmetrical current basis is that the symmetrical short-circuit interrupting ampere level required for an application can be calculated much more easily. Ohms Law or any other method of circuit analysis can be used. IEEE Std 551™ (*IEEE Violet Book™*) [B11] discusses different methods for calculating short-circuit currents. Circuit breaker evaluation is then made on the basis of the application circuit X/R ratio as compared with the test circuit X/R ratio. Tables of X/R facilitate the evaluation.

Short-circuit testing is done to confirm that a given frame size circuit breaker is capable of withstanding the heat and forces of a short-circuit interruption and that it can protect the conductors connected to it. The standards require proof testing of a circuit breaker's ability to interrupt bolted faults. When a circuit breaker of a given ampere rating is chosen for an application, its interrupting rating is chosen to be equal to or greater than the calculated short-circuit symmetrical current of the supply system at the point where the circuit breaker is to be connected to the supply system. The current calculated for this condition is called the prospective fault current. The actual fault current can never reach this level because there is always additional impedance added between the point of circuit breaker connection to the supply bus and the load side of the circuit breaker. The connections and the circuit breaker impedance are between those points.

The short-circuit interruption testing specified in standards takes this into account in different ways. For more discussion of the fault calculation process and the effect of fault impedance on the results, see IEEE Std 141-1993 (*IEEE Red Book™*) [B4]. Generally, for LVPCB testing details, see ANSI C37.50-2012, and for MCCBs and ICCBs, see UL 489.

The short-circuit current interrupting rating of a circuit breaker is that value of symmetrical short-circuit current that would flow in the circuit where the circuit breaker is to be connected for test. This test prospective fault current is actually a measured value of current to confirm that the proper test conditions

exist. The X/R ratio in the prospective test current circuit is set to the value specified for it in the applicable circuit breaker standard. The circuit breaker is tested to prove that it is able to safely interrupt the fault current that actually flows from this circuit during the test.

The short-circuit current interrupting requirement for a circuit breaker to be applied in a practical system is called the prospective fault current for that system and is the value of symmetrical short-circuit current mathematically calculated for that system at the point of circuit breaker application. The process of determining whether the circuit breaker rating is sufficient to interrupt the prospective application circuit fault-current is called circuit breaker evaluation. More discussion of the circuit breaker evaluation process follows.

4.29 Fault-current calculation considerations

Short-circuit application duty requirements for circuit breakers are calculated the same way for all types of circuit breakers. As all circuit breakers are now rated on a symmetrical current basis, the initial step is an Ohm's Law solution of the symmetrical three-phase circuit. The short-circuit interrupting duty requirement for a circuit breaker is taken to be the short-circuit capacity of the power system at the point in the power system where the circuit breaker is to be connected. As discussed, it leads to conservative results because neither connection impedance, circuit breaker impedance, fault-circuit impedance, nor arc impedance is taken into account in this calculation. Furthermore, and better from the point of view of consistency, the results of the Ohm's Law system study calculations are essentially the same no matter which engineer does the calculation (provided commonly accepted power system data are used). Finally, any correction needed to account for fault-circuit power factor less than the value used for testing (or for X/R ratio greater than that used for testing) is applied. This is most often done by multiplying the fault current by a multiplying factor that is a function of the system X/R. A separate discussion of the effects of X/R ratio follows in this chapter. IEEE Std 551™ (*IEEE Violet Book*™) [B11] is an excellent reference for further study of the process of calculation.

4.30 Circuit breaker interrupting ratings

Recognized current interrupting ratings for MCCBs and ICCBs are listed in Table 17. The preferred short-circuit interrupting ratings of LVPCBs are listed in Table 8, Table 9, and Table 10. Circuit breakers are designed with the goal of achieving one of these ratings.

**Table 17 —Current interrupting ratings for MCCBs and ICCBs—
rms symmetrical or dc amperes**

7500	25 000	65 000
10 000	30 000	85 000
14 000	35 000	100 000
18 000	42 000	125 000
20 000	50 000	150 000
22 000	—	200 000

Source: Table 8.1 of UL 489-2013

MCCBs and ICCBs are tested in the prospective fault test circuit by connecting the circuit breaker on test in place of the shorting bus links used for test-circuit calibration. The connections are made with lengths of rated wire or bus in accordance with UL 489-2013. The prospective current source or test laboratory source remains as set during calibration. Power factor values for the test circuit are as given in Table 18.

Table 18 —Test-circuit power factor for testing MCCBs and ICCBs

Test circuit (A)	Power factor
10 000 or less	0.45-0.50
10 001-20 000	0.25-0.30
Over 20 000	0.15-0.20

Source: Table 7.1.7.4 of UL 489-2013

LVPCBs can be included in the prospective current test circuit when that circuit is being calibrated for testing. Shorting links are used to complete the test circuit for calibration, and when the circuit is calibrated, the circuit breaker to be tested is connected into the prospective circuit to replace the short-circuiting links. Tests are then performed to satisfy one of the preferred short-circuit interrupting ratings given in Table 8 through Table 10.

4.31 Single-pole fault interruption testing

Single-pole, maximum line-to-line voltage testing is done at the theoretical maximum single-phase fault-current level of 87% of maximum bolted three-phase fault current on all LVPCBs. Some MCCBs are tested similarly except at full-rated voltage that is equal to their maximum voltage. Other MCCBs are single-pole tested in a similar manner at the same full-rated voltage but at a reduced fault-current level. Table 19 and Table 20 show the test current values used.

Single-pole ratings become a matter of concern in low-voltage systems that are impedance grounded or ungrounded. In such systems it is possible that line-to-line faults occur between two circuit breakers. In that case, a single pole of a single circuit breaker may be called upon to interrupt high levels of fault current at full phase-to-phase voltage. Single-pole testing confirms the circuit breaker is capable of performing that interruption safely. Circuit breakers that do not have sufficient single-pole ratings should not be used in equipment able to deliver fault current in excess of the device's single-pole rating. This is one reason why low-voltage switchgear with LVPCB is typically used in industrial applications where high-resistance grounding is implemented instead of using switchboards with MCCB. See 4.41 for further details.

4.32 Circuit breaker evaluation in standards for testing

Voltage, symmetrical short-circuit current magnitude, and circuit X/R ratio, as seen from the point of circuit breaker connection to the power system, are the factors that should be known to evaluate a circuit breaker. If a circuit breaker has not been tested to IEEE or UL testing standards, it may be very difficult or impossible to evaluate. Because a circuit breaker is applied according to its rating, the method of testing that was used to establish that rating should be understood in order to be able to conduct an evaluation. If a circuit breaker's interrupting capability cannot be evaluated, it should not be applied.

Current IEC practices and standards do not directly correspond to the practices and standards in use in North America for single-pole duty, thermal response, or grounding. This can make it very difficult at best to make comparison evaluations between domestic and IEC circuit breaker capabilities. UL 489, IEEE Std C37.14 and ANSI C37.50 short-circuit testing procedures and parameters are tabulated for reference in Table 21 through Table 23. These tables show how the differences between procedures can complicate direct comparison.

Table 19—Available current in test circuits

Frame rating	RMS symmetrical or dc amperes				
	1 pole	2 pole		3 pole	
		Individual ^a	Common	Individual ^a	Common
100 A maximum	5000	5000	5000	4330 ^{b,c}	5000
250 V maximum					
100 A maximum	10 000	10 000	10 000	8660 ^{b,c,d}	10 000
251 V – 600 V					
101 A – 800 A	10 000	10 000	10 000	8660 ^{b,c,d}	10 000
801 A – 1200 A	14 000	14 000	14 000	12 120 ^{b,d}	14 000
1201 A – 1600 A	—	14 000	20 000	14 000	20 000
1601 A – 2000 A	—	14 000	25 000	14 000	25 000
2001 A – 2500 A	—	20 000	30 000	20 000	30 000
2501 A – 3000 A	—	25 000	35 000	25 000	35 000
3001 A – 4000 A	—	30 000	45 000	30 000	45 000
4001 A – 5000 A	—	40 000	60 000	40 000	60 000
5001 A – 6000 A	—	50 000	70 000	50 000	70 000

^aAt the option of the manufacturer, the adjustable response of a circuit breaker that incorporates a delayed-tripping element may be adjusted to less than the maximum position for the individual pole tests.

^bThis value is the current available when using two legs of the 3-phase circuit indicated under “Common.”

^cFor dc ratings, the current indicated under “Common” is to be used for individual pole operation.

^dFor the 208Y/120 V, 480Y/277 V, or 600Y/347 V rating, the current indicated for 2-pole under “Individual” shall be used.

Source: Table 7.1.7.2 of UL 489-2013

Table 20—Available current in test circuits^a

Frame rating	RMS symmetrical or dc amperes	
	1-pole	2-pole and 3-pole
		Common
100 A maximum		
250 V maximum	1500	1500
100 A maximum	3000	3000
251 V – 600 V maximum		
101 A – 225 A	3000	3000
226 A – 400 A	5000	5000
401 A – 600 A	6000	6000
601 A – 800 A	10 000	10 000
801 A – 1200A	14 000	14 000
1201 A – 1600 A	—	20 000
1601 A – 2000 A	—	25 000
2001A – 2500 A	—	30 000
2501 A – 3000 A	—	35 000
3001 A – 4000 A	—	45 000
4001 A – 5000 A	—	60 000
5001 A – 6000 A	—	70 000

^aSequence of operations shall be O-t-CO, where t is a minimum of two min and a maximum of one h.

Source: Table 7.1.7.3 of UL 489-2013

Table 21 —Short-circuit current tests

Test	Duty cycle	Type of test (No. of phases)	Rated maximum voltage	Current
1	O-15 s-C-O	3	635	I_1
2	O-15 s-C-O	3	508	I_2
3	O-15 s-C-O	3	254	I_3
4	O-15 s-C-O	1	635	$0.87 I_1$
5	O-15 s-C-O	1	508	$0.87 I_2$
6	O-15 s-C-O	1	254	$0.87 I_3$
7	O	3	635	I_1
8	O-15 s-C-O	3	635	I_8
9	O	1	600	174 000
10	O+t+C-O	3	600	200 000
11	O	3	600	See 4.9.2.3 of ANSI C37.50-2012
12	O	3	600	See 4.9.2.4 of ANSI C37.50-2012

NOTE 1—O = opening operation; C-O is close-open; t = time necessary for the test procedures, including replacement of fuses and resetting of the open-fuse trip device; I_1 = rated short-circuit current at rated maximum voltage of 635 V; I_2 = rated short-circuit current at rated maximum voltage of 508 V; I_3 = rated short-circuit current at rated maximum voltage of 254 V (selected from Table 1 of IEEE Std C37.16-2008); I_8 = rated short-circuit current at rated maximum voltage of 635 V (selected from Table 2 of IEEE Std C37.16-2008).

NOTE 2—Test 1 and test 2 are to be performed with opposite terminals energized (e.g., if upper terminals are used for test 1, then lower terminals are used for test 2, and vice versa).

NOTE 3—Test 2 is to be performed in sequence II given in Table 1 of ANSI C37.50-2012, using a circuit breaker equipped with the minimum-rated continuous-current electromechanical overcurrent trip device for the circuit breaker frame size being tested.

NOTE 4—Test 4, test 5, and test 6 may be performed on the same circuit breaker, one test per pole.

NOTE 5—For test 9 and test 10, the current is in rms symmetrical amperes.

NOTE 6—For tests 11 and 12 see the referenced sections of ANSI C37.50-2012.

NOTE 7—At the option of the manufacturer, test 11 may be omitted if the total clearing time of the maximum fuse is equal to or less than the minimum total clearing time of the circuit breaker element, at the short-circuit test current value. If the circuit breakers time current characteristic data are for the maximum clearing time, subtract 0.016 second to obtain a value for the minimum total clearing time of the circuit breaker element.

Source: Table 3 of ANSI C37.50-2012

Table 22 – MCCB and ICCB short-circuit test summary

	Test no.	Tested in sequence no.	Duty cycle	No. of poles being tested	Max rated voltage	Actual test current rms symmetrical kA										
						Frame rating (A)										
						100 ^a	100 ^a	225 ^a	600 ^a	800 ^a	1200 ^a	1600 ^a	2000 ^a	2500 ^a	3000 ^a	4000 ^a
Standard tests	1	Z	O-CO	1	250	4.3	—	—	—	—	—	—	—	—	—	—
	2	Z	O-CO	1	600	—	8.6	8.6	8.6	8.6	12.1	14	14	20	25	30
	3	Z	O-CO	1	600	—	8.6	8.6	8.6	8.6	12.1	14	14	20	25	30
	4	Z	O-CO	1	600	—	8.6	8.6	8.6	8.6	12.1	14	14	20	25	30
Standard tests	5	Z	O	3	250	5	—	—	—	—	—	—	—	—	—	—
	6	Z	O	3	600	—	10	10	10	10	14	—	—	—	—	—
	7	Z	O-CO	3	600	—	—	—	—	—	—	20	25	30	35	45
	8	Y	O-CO	3	240	1.5	—	—	—	—	—	—	—	—	—	—
	9	Y	O-CO	3	600	—	3	3	6	10	14	20	25	30	35	45
High I/C tests	Test no. ^b	Duty cycle	No. of poles	Trip rating	Actual test current											
	A ^a	O-CO	3	Maximum	Same as maximum interrupting capacity (I/C) rating											
	B ^a	O-CO	3	Maximum	I/C rating at maximum voltage rating											
	C ^a	O-CO	3	Maximum	I/C at maximum kVA rating											
	D ^a	O-CO	3	Maximum	Maximum I/C rating											

^aAll tests at each rating in sequence Z must be successfully passed with a single breaker.

^bEach test may use a new breaker.

Source: Panel Discussion on Application of Molded-Case Circuit Breakers [B20]

Table 23—UL and IEEE short-circuit test parameters

Parameter	UL 489-2013		ANSI C37.50-1989
Enclosure	Smallest individual		Min dimension test enclosure
Current	Per Table 7.1.7.2 and Table 7.1.7.3 of UL 489-2013		Per Table 4 of IEEE Std C37.50-1989
Voltage	100%-105% rated		100%-105% rated max (254 V, 508 V, or 635 V)
Power factor (ac)	10 000 or less	0.45-0.50	0.15 max lagging
	10 001-20 000	0.25-0.30	
	Over 20 000	0.15-0.20	
Time constant (dc)	10 000 or less	3 ms	Not covered
	Over 10 000	8 ms	
Frequency	48-62 Hz		48 Hz-72 Hz
Ambient	Not defined		10 °C-40 °C
Ground fuse	30 A		30 A or 10 AWG (copper)
NOTE 1—Random closing employed.			
NOTE 2—Time interval between interrupting operations: 2 min to 1 h maximum.			

Source: UL 489-2013 and ANSI C37.50-2012

Field testing by manual methods often produces results that are not in agreement with the manufacturer's tests and are not accurate indicators of circuit breaker performance. It is difficult to justify a high-quality test setup anywhere except at a manufacturing facility, so differences between factory and field test results should be expected. Offset in the test current wave invalidates results.

When testing, it is always important to make sure the trip unit installed is the one represented by the referenced specifications or time-current curves. Interchangeable trip units often look similar but may be different. MCCBs, for example, may have thermal-magnetic trip units or electronic trip units. If they have electronic trip units, the electronic trip units may be peak-sensing or rms-sensing and they may or may not include ground-fault tripping provisions. Furthermore, newer electronic trip units feature built-in test provisions that are easy to operate and can even be operated in a no-trip mode while the circuit breaker is under light load.

An alternative to using the built-in provisions, secondary or primary current injection methods can be employed using external test equipment. Current injection tests, of course, require the circuit breaker to be taken out of service. Thermal overload trip units using bimetallic sensors respond to the rms value of the current flowing through them and their heaters. Electronic overload trip units may be either peak-sensing or rms-sensing depending on their internal circuit design. That is, they can be designed to respond to the peak value of the current flowing through them or to the rms value of current flow. The engineer should always keep these factors in mind when evaluating alternative circuit breaker and trip-unit choices.

The response of a bimetallic trip unit on circuit breakers will be different if the energy input to the trip unit as a whole is different. For example, if only one pole is carrying current, then only one bimetallic element is being heated and pressing on the trip bar, and in general, a slightly longer trip time should be expected. This fact is indicated by the single-pole test characteristic printed above the long-time, time-current curve on typical circuit breaker data sheets. The shorter time characteristic below it is indicative of performance, per standards, with equal current flow in all poles.

Instantaneous electromagnetic pickup (tripping) in thermal-magnetic circuit breakers is, in fact, a function of peak current flow even though the abscissa of the time-current curve is labeled in rms amperes. The reason is because the magnetic flux and the force the magnetic flux produces in the operating mechanism of the trip unit is a function of current alone, not power. In like manner, a peak-sensing electronic trip unit can respond with a trip to a single current surge or spike that reaches the circuit trip level. Even electronic trip units using rms-sensing algorithms can be triggered to produce an override instantaneous trip if a current surge or spike large enough to activate the override is experienced. The override trip is an independent instantaneous trip set near the circuit breaker withstand level that overrides the electronic logic trip unit to cause the circuit breaker to open without delay at very large fault levels. Therefore, circuit breaker

application evaluations should take into account not only the salient features of the test specifications cited above, but also the requirements and characteristics of the circuit breaker trip unit and the circuit breaker itself. Every aspect of circuit breaker design, circuit operation, and system maintenance can affect overall operational performance.

4.33 Blow-open contact arms

Most MCCBs achieve high interrupting rating levels because they are designed to use the fault current to drive tripping action. Within the limits of rating, it can be generalized that the larger the fault-current flow, the greater the driving force and the quicker the trip and interruption. Most MCCBs trip and interrupt fast enough to limit the peak and I^2t let-through of fault current. Some satisfy the requirements of current-limiting circuit breakers as defined in Clause 3. LVPCBs, on the other hand, trip only after their trip units initiate a mechanism release. Then fault current can contribute driving force.

If an MCCB is claimed to be current-limiting, UL 489 requires that the peak current and I^2t be tabulated for the threshold of current limiting, the maximum interrupting level, and at least one point in between. A curve to present these data is usually drawn and published for user reference. Such a tabulation and curve are not required for circuit breakers not claimed to be current-limiting.

It should be noted that any circuit breaker experiencing fault current above its withstand level may experience contact parting due to magnetic forces generated within the contact structure even if the device is not specifically designed to be current-limiting. The contact parting resulting from the magnetic forces generated is called contact popping. The contact popping is a short-term parting of the contact that will produce an arc and consequent arcing voltage. The arc voltage will result in current-limiting-like behavior. Though the degree of limitation may be less than that expected of a purposely designed current-limiting circuit breaker, it will result in dynamic circuit impedance under fault conditions. This dynamic fault impedance has an effect on selectivity and potential series ratings. Manufacturers take this phenomenon into consideration via sophisticated analysis, testing, or both when generating special selectivity tables or UL-recognized series ratings.

4.34 Circuit breaker useful life

It is prudent to replace any MCCB that has interrupted, at most, two faults at rated maximum current. The reason is that the MCCB short-circuit proof test consists of an O-t-CO sequence, which means that in proof testing of the circuit breaker design and in periodic follow-up testing thereafter, the circuit breaker is required to open a fault from an initially closed position (corresponding to the O operation), then after a period of time (t) to reset is allowed, to be closed into a maximum fault and trip open for a second time (corresponding to the CO operation). This process demonstrates a circuit breaker's ability to perform at least two maximum-level fault interruptions, with the second at least a little worse than the first. No maintenance of the circuit breaker on test is permitted between interruptions.

The problem, of course, is that fault-current levels are not usually monitored. It is difficult and expensive to tell whether a fault was a maximum fault, and in general, low-voltage system faults tend to be less than maximum. Therefore, circuit breaker inspections should be performed according to a plan developed to suit the application. NEMA AB 4 [B15] should be referenced for MCCB and ICCB field inspection and maintenance.

LVPCBs go through similar short-circuit test cycles, but it is generally not said that LVPCBs need to be replaced after a given number of fault interruptions because they can and should be inspected for wear and damage and they should be refurbished or repaired as required after interrupting faults and before being restored to service. The fact that LVPCBs can even be maintained between tests emphasizes the maintainability feature of their design and further distinguishes them from MCCBs and ICCBs. See note

(3) of Table 1 of ANSI C37.50-2012 for some specific detail on LVPCB testing. Maintenance is necessary if continued reliable service is to be expected.

4.35 Considerations on interrupting duty and maintenance

As discussed in 4.34, one problem associated with the implementation of good system operating and maintenance procedures is that it is generally difficult to determine whether a fault that has occurred was a maximum-level or bolted fault. Another factor is that without inspection, the actual condition of any circuit breaker cannot be known. Time and money must be spent to implement both procedures. Some new digital microprocessor-based trip units store fault-current magnitude data, both phase and ground, in memory when a trip occurs and that data can be read at the time of inspection, which helps the engineer determine the seriousness of a trip condition.

For the ultimate in reliability, the engineer should assume that the fault could have damaged any of the circuit elements, including the conductors, and a complete inspection of the circuit is required. MCCBs, ICCBs, and LVPCBs should be inspected in proportion to the required reliability of their service and as a minimum in observance of the recommendations given in standards and instruction leaflets. For a detailed discussion of MCCB inspection procedures, see NEMA AB 4 [B15] in particular, and for a detailed discussion of circuit breaker reliability in general, see IEEE Std 493 (*IEEE Gold Book*TM) [B9]. LVPCB, MCCB, and ICCB maintenance and inspection procedures can be found in the instruction leaflets and documentation furnished by circuit breaker manufacturers. These documents should be read by system operating personnel upon receipt of the equipment, and they should be kept on file for future reference. Maintenance personnel should incorporate pertinent practices and procedures into their own maintenance policies. The benefits of proof testing can be lost if inspection and maintenance policies are not implemented.

4.36 Integrally fused devices

Integrally fused LVPCBs and MCCBs with inverse time or instantaneous automatic tripping may have interrupting capacities much greater than those of unfused circuit breakers of corresponding frame sizes, and they are intended primarily for overcurrent and/or short-circuit protection of high-capacity electrical circuits. When applied on high short-circuit current capacity systems, the effects of the let-through characteristics of the fused circuit breakers on the connected equipment should be considered. The presence of the current-limiting fuse as part of the fused circuit breaker does not necessarily imply that the connected equipment can adequately withstand these effects.

It should be noted that fused circuit breakers do not generally have any current-limiting effect until the current associated with the fault exceeds the current-limiting threshold of the fuse. When fuses of relatively low continuous current rating and relatively low peak let-through current rating are selected to give protection to downstream equipment, there is increased likelihood that they will open at currents much below the circuit breaker element short-circuit current rating. If the full coordination study for the protection of connected equipment is made known to the manufacturer, then the best combination of direct-acting trip devices and fuses may be selected. Non-optimum combinations can lead to needless fuse opening. In no case should combinations of trip devices and fuses that are not approved by the manufacturer be installed.

Where fuses of different manufacture are being considered for the same system, the characteristics of all fuses and circuit breakers in the system should be evaluated because both the melting time current characteristics and the peak let-through currents of a given fuse rating may vary substantially between manufacturers. Only fuses that have been proof tested with the circuit breakers should be used.

4.37 Series-connected ratings

Series rated circuit breakers may be used to provide lower cost circuit protection than a series of fully rated circuit breakers. Such series rated devices should be UL recognized for the purpose. Motor contribution from other circuits not part of the series rating can cause downstream devices to not be properly protected hence the NEC contains specific limits on such contribution; series combinations are restricted to use in circuits motors are not connected on the load side of the higher-rated overcurrent device and on the line side of the lower-rated overcurrent device and the sum of the motor full-load currents exceeds 1% of the interrupting rating of the lower-rated circuit breaker.

Sometimes it is erroneously thought that series combinations are at a disadvantage with regard to coordination as compared with fully rated systems. The fact is that even fully rated circuit breakers with instantaneous trips may not coordinate once the fault level exceeds both circuit breakers' instantaneous trip levels. An IEC viewpoint extends this concept somewhat by definition of the term discrimination, which recognizes that energy is required to cause a circuit breaker to trip, and even though the straight vertical lines and flat horizontal segments commonly used to describe the instantaneous trip range of a circuit breaker are drawn, there is some range of overlap of these zones where tripping of both circuit breakers does not occur. The process of discrimination defines these areas so they can be added to the range of selectivity indicated by the time-current curves. The interested reader should refer to IEC 60947-2 [B3] for more detail. Because there are enough opportunities to make series rating an advantage to users and the concept of series ratings may be easily misapplied, a test protocol and subsequent series ratings and listings have been established by the UL and are recognized in the NEC.

Series connection of MCCBs, where the branch or downstream circuit breaker has an interrupting rating less than the calculated fault duty at its point of connection in the power circuit, is permitted only when the series combination has been proven to be safe by actual interruption testing. Domestically, a series combination is recognized for series application by a third-party organization such as the UL.

Series ratings should not be confused with the older domestic calculated cascade ratings discussed in 4.38. It should be noted that the IEC uses the term cascade to describe its series rated and tested circuit breaker combinations and the term discrimination to describe the ability of a load-side series-connected circuit breaker to actually coordinate with a line-side circuit breaker over some portion of their indicated mutual instantaneous trip range. Fundamentally, series ratings are proven by test, whereas the no-longer-valid cascade arrangements of the past were determined by calculation procedures that are no longer accepted as generally adequate.

NEC Section 110.22 acknowledges that manufacturers can establish series combination ratings and it requires that equipment enclosures "...shall be legibly marked in the field...Caution—Series Rated System" to indicate that the rules for series application were utilized to design this part of the power distribution system.

This marking becomes part of the application. NEC Section 240.86 also acknowledges the use of series ratings and the requirements for marking. Section 7.13 of UL 489-2013 outlines the test connections and procedures required for proof of series combination ratings.

Series rating of two circuit breakers makes it possible to apply the two in series, as one device, with the interrupting rating being the series rating of the combination. In summary, it is not permissible to calculate series ratings because accurate and sufficiently uncomplicated methods for doing so have not been identified at this time.

4.38 Cascade arrangement

Previously, in practice, there was a circuit breaker arrangement known as a cascade arrangement in which circuit breakers were essentially applied in series. However, the adequacy of the cascade arrangement was

determined by calculation, not by testing, and the calculation methods have since been determined to be generally inadequate. As the cascading method does not include verification by testing, it is no longer a recommended procedure for applying circuit breakers. UL 489 does not address the subject of cascade arrangements generally for MCCBs, whereas IEEE Std C37.13 specifically states that it is no longer a recommended procedure for LVPCBs. If coordination considerations will permit the application of a series combination, then only tested and listed series combinations of circuit breakers can be applied and the markings of equipment discussed above should be employed. Otherwise, fully rated circuit breakers should be applied at all locations in the circuit with interrupting ratings equal to or greater than the evaluated prospective fault current at the point of application.

4.39 Short-time rating

Short-time ratings are not covered in MCCB standards because MCCBs are applied in apparatus that do not have short-time withstand ratings (see UL 891 and UL 508). As a consequence, MCCBs are designed to trip and interrupt high-level faults without intentional delay and are not designed to close and latch onto a fault. However, newer electronic trip units usable with some MCCBs are able to use the capabilities of some of these circuit breakers to implement short-delay tripping. ICCBs generally do have short-time capability because their closing and tripping mechanisms are more like those of LVPCBs, not designed to blow open, and they generally have more current withstand capability. LVPCBs are designed to have a close and latch rating capability that defines the level of fault current the circuit breaker can close into, and short-time capability that can withstand the short-time duty cycle test. They are designed to be tripped by a shunt trip device, though the shunt coil may be several milliseconds slower than the coil, called a flux shifter, used by the integral trip unit.

For an unfused LVPCB, the rated short-time current is the designated limit of available (prospective) current at which it shall be required to perform its short-time current duty cycle of two periods of 0.5 s of current flow separated by a 15 s interval of zero current at rated maximum voltage under the prescribed test conditions. This current is expressed as the rms symmetrical value of current measured from the available current wave envelope at a time one half-cycle after short-circuit initiation.

Unfused LVPCBs shall be capable of performing the short-time current duty cycle with all degrees of current asymmetry produced by three-phase or single-phase circuits having a short-circuit power factor of 15% or greater (X/R ratio of 6.6 or less). Preferred short-time current ratings are shown in Table 9.

Fused LVPCBs do not have short-time ratings. No short-test is defined in the standards for the circuit breaker element of a fused circuit breaker because the fuse will not allow current flow for the time needed to demonstrate a short-time rating.

Some circuit breakers, such as LVPCBs and ICCBs, have a short-time withstand rating higher than their close and latch capability, making the implementation of a making current release (MCR) function necessary. The MCR function is analogous to a very fast instantaneous trip that is only functional when the circuit breaker is closing. If the circuit breaker attempts to close into a fault current above the MCR threshold, the circuit breaker will not latch and will immediately open. This function protects the circuit breaker from attempting to close in on a large magnitude fault beyond its capability to latch. MCRs are typically set significantly higher than normal transient currents and require substantial fault current to operate them. LVPCBs that have a close and latch rating equal to the interrupting rating are not furnished with an MCR function.

4.40 Circuit breaker evaluation for X/R ratio or short-circuit power factor

LVPCBs in general are evaluated for short-circuit interrupting capability on a first-half-cycle basis. As indicated, MCCBs can sometimes operate so quickly that they function in a current-limiting mode, which

means they operate to limit short-circuit current before the first current peak is reached. As the peak current is a function of the offset of the rms symmetrical current wave, which is in turn a function of the power factor or the X/R ratio of the circuit, the fact that:

- LVPCBs are tested with an X/R ratio of 6.6 (4.9 for fused), and
- MCCBs and ICCBs are tested with X/R ratios of 6.6 to 4.89, 3.8 to 3.18, and 1.98 to 1.75, depending on interrupting rating,

means they have to be evaluated differently. See Table 18 for a listing of the power factor ranges from which the MCCB and ICCB X/R ratio ranges are derived.

If a circuit has an X/R ratio less than the value used for proof testing a given circuit breaker, then no adjustment in that circuit breaker's interrupting rating is required and the circuit breaker can be evaluated by direct comparison of its short-circuit interrupting current rating with the calculated Ohm's Law symmetrical short-circuit fault-current calculation. Another way of understanding that statement is to understand that an increase in the short-circuit interrupting capability of a circuit breaker may never be claimed by virtue of a mathematical calculation alone.

On the other side of the X/R inequality, if the calculated value of the short-circuit X/R ratio is greater than the value used to test the circuit breaker, then the interrupting duty requirement of that application has to be increased by multiplying the calculated symmetrical short-circuit current magnitude by a multiplying factor (MF) greater than one, which is equal to the ratio of the offset peak of the calculated circuit divided by the offset peak of the test circuit. This means that the offset current for the calculated fault is greater than the offset current of the circuit breaker test circuit and that the circuit breaker should therefore have the capability to interrupt MF times the calculated Ohm's Law value of the symmetrical short-circuit current when applied in that circuit.

Looking at this from the point of view of de-rating the circuit breaker instead of up-rating the short-circuit current, it could be said that the circuit breaker rated interrupting capacity should be de-rated by a factor equal to the reciprocal of MF (or 1/MF) because the peak fault current with this larger X/R condition is greater than the peak current of the circuit breaker test circuit.

In summary, the calculated Ohm's Law symmetrical short-circuit current can be multiplied by an MF to indicate the true interrupting requirement of the circuit, or the short-circuit interrupting rating of the circuit breaker can be de-rated by multiplying its short-circuit interrupting rating by (1/MF) to indicate the circuit breaker's capacity to interrupt current on the new higher X/R basis. Both approaches are commonly used. See Table 24 for multiplying factors.

4.41 Single-pole interrupting capability and power system design considerations

For the rated X/R condition, every three-pole circuit breaker intended for use on three-phase circuits is able to interrupt a bolted single-phase fault. Obviously, it should have this capability because single-phase faults not only cannot be prevented from occurring on three-phase systems, but they are also probably the most likely to occur.

When interrupting a single-phase, line-to-line fault in a three-phase circuit, there are two circuit breaker poles in series performing the interruption with line-to-line voltage impressed across the two poles in series. Theoretical maximum single-phase prospective fault current is therefore 87% of the full three-phase bolted fault current. This interrupting duty is less severe than for a three-phase interruption test where the first pole to open can have a maximum of one and one-half times peak phase voltage impressed across that pole alone and the theoretical maximum three-phase prospective fault current is by definition 100%. Therefore, three-phase interruption tests also prove single-phase interrupting capability of three-pole circuit breakers.

However, if the three-phase power system is corner grounded, then a single-line-to-ground fault on the load side of the circuit breaker will result in single-phase fault current flowing through only one pole of the circuit breaker, but with line-to-line voltage impressed across that one pole. A review of the test specifications referenced will show that all LVPCBs are tested to prove single-pole interrupting capability at the 87% current level with maximum line-to-line voltage impressed across that one pole (see Table 20). But not all MCCBs and ICCBs receive the same 87% current, full line-to-line voltage single-pole test. All MCCBs and ICCBs are tested for single-pole performance at rated line-to-line voltage, but some are tested at lower than 87% of maximum fault-current level. As in all applications, it is necessary to calculate the interrupting requirement of the circuit and to apply a circuit breaker with the required interrupting rating. See Table 19 for the different individual levels. See also Figure 13 for additional information on corner grounded delta systems. Finally, similar application requirements must be observed with impedance grounded wye and ungrounded delta systems when there is a potential that there could be two faults on the system at the same time, resulting in full line-to-line voltage being impressed across one pole of the circuit breaker. See further information on impedance grounded systems in Figure 10 and on ungrounded delta systems in Figure 11.

Table 24—Selection of short-circuit current multiplying factor for MCCBs and LVPCBs

Power factor (%)	X/R ratio	MCCB interrupting rating (rms symmetrical A)			LVPCB	
		10 000 or less	10 001 to 20 000	Over 20 000	Unfused	Fused
Short-circuit current multiplying factor						
4	24.98	1.62	1.37	1.23	1.16	1.23
5	19.97	1.59	1.35	1.22	1.14	1.22
6	16.64	1.57	1.33	1.20	1.12	1.20
7	14.25	1.55	1.31	1.18	1.11	1.19
8	12.46	1.53	1.29	1.16	1.10	1.18
9	11.07	1.51	1.28	1.15	1.09	1.15
10	9.95	1.49	1.26	1.13	1.07	1.14
11	9.04	1.47	1.24	1.12	1.05	1/12
12	8.27	1.45	1.23	1.10	1.04	1.11
13	7.63	1.43	1.21	1.09	1.02	1.10
14	7.07	1.41	1.20	1.08	1.01	1.08
15	6.59	1.39	1.18	1.06	1.00	1.06
16	6.17	1.38	1.17	1.05	1.00	1.05
17	5.8	1.36	1.15	1.04	1.00	1.04
18	5.49	1.35	1.14	1.02	1.00	1.03
19	5.17	1.33	1.13	1.01	1.00	1.02
20	4.9	1.31	1.11	1.00	1.00	1.00
21	4.86	1.31	1.11	1.00	1.00	1.00
22	4.43	1.28	1.09	1.00	1.00	1.00
23	4.23	1.27	1.08	1.00	1.00	1.00
24	4.05	1.26	1.06	1.00	1.00	1.00
25	3.87	1.24	1.05	1.00	1.00	1.00
26	3.71	1.23	1.04	1.00	1.00	1.00
27	3.57	1.22	1.03	1.00	1.00	1.00
28	3.43	1.20	1.02	1.00	1.00	1.00
29	3.3	1.19	1.01	1.00	1.00	1.00
30	3.18	1.18	1.00	1.00	1.00	1.00
35	2.68	1.13	1.00	1.00	1.00	1.00
40	2.29	1.08	1.00	1.00	1.00	1.00
45	1.98	1.04	1.00	1.00	1.00	1.00
50	1.73	1.00	1.00	1.00	1.00	1.00

Source: Table 7.7 of IEEE Std 242™-2001 (*IEEE Buff Book™*) [B7]

Figure 6 shows the circuit connections for the tests of one-, two-, and three-pole MCCBs tabulated in the operations columns of Table 3. From these connections, the different connections used for straight voltage rated, slash voltage rated, and single-pole tests can be seen. It is therefore necessary to treat MCCB applications in corner-grounded systems differently from applications of LVPCBs. Generally, the circuit breaker manufacturer should be consulted whenever corner-grounded system applications are involved.

For a wider perspective on this situation, IEC rated circuit breakers are not required to receive regular single-pole tests. The single-pole interrupting capacity aspect of performance is addressed in Appendix C of IEC 60947-2 (2006) [B3] only for “...multi-pole circuit breakers intended for use on phase-earthed systems...” and then only at a prospective current “...equal to 25% of the ultimate rated short-circuit breaking capacity....”

Outside the situations of application in a corner-grounded system or double jeopardy on improperly operated, ungrounded, or high-resistance grounded systems, which require the occurrence of simultaneous bolted faults on the line side and the load side of a circuit breaker to get even the possibility of 87% current, single-pole interrupting capability has not been a major application factor worldwide over the last half-

century. Circuit breaker sales literature notes cover the intentional corner-grounded system application contingency by noting that if the power system is corner-grounded, then the purchaser should contact the factory for application assistance.

Power system design engineers should first determine the type of power system to be used with due consideration for its practical implementation, which means that if power systems are to be designed to be operated ungrounded or with high-resistance grounding, then it should be specified that they should be operated in accordance with the operating procedures set forth for such systems. For more detailed discussion on power system design considerations and their operation, the interested reader is referred to IEEE Std 141™-1993 (*IEEE Red Book*™) [B4].

4.42 Applying ac thermal-magnetic molded-case circuit breakers using their UL 489 dc rating

Under the provisions of UL 489 (the standard upon which the designs of molded-case circuit breakers are based), some thermal-magnetic molded-case circuit breakers can have dc ratings assigned. When dc ratings are assigned to these molded-case circuit breakers, the dc voltage levels and their corresponding interrupting ratings are indicated on the circuit breaker faceplate, on the circuit breaker's time-current-curves (TCCs) and on circuit breaker data sheets. Just as ac interrupting ratings differ with voltage rating, different dc interrupting ratings apply at different dc voltage levels, and the dc interrupting ratings are subject to de-rating for application voltage as is done for ac circuit applications.

Obviously, dc current interruption is different from ac current interruption. Alternating sinusoidal short-circuit fault current usually passes through zero magnitude at least twice each cycle. These zero crossings are helpful in the ac interrupting process. DC short-circuit fault current does not normally go through a zero value. It is best characterized as a uni-directionally increasing exponential current approaching a limiting value. To interrupt dc current, the circuit breaker must produce all of the physical effects required to reduce the dc current to zero magnitude and thereafter maintain an open circuit.

As there is no difference in the heating ability of effective rms ac current and dc current, the long-time trip characteristic or the thermal trip characteristic of a thermal-magnetic circuit breaker is the same for ac and dc. This finding means that the thermal part of the TCC remains the same for both ac and dc applications. It is only in the instantaneous trip region where the current waveforms are different that a correction factor may need to be applied. The characteristic curve shape remains the same, but the abscissa current magnitude value changes. For that reason, it is simple and economical to state the correction factor for current magnitude in this range of the TCC and not to complicate the presentation with another set of abscissa values. How to deal with this difference is addressed by circuit breaker manufacturers in application notes or on the circuit breaker TCC and on data sheets.

4.42.1 Consequences of the difference between instantaneous ac symmetrical rms current and dc current for instantaneous trip

The magnetic trip devices in thermal-magnetic circuit breakers that initiate an instantaneous trip operate on magnetic force produced by the instantaneous fault current itself. Here, the difference between instantaneous dc current and instantaneous ac rms current for the same numerical value must be taken into account. The theoretical instantaneous peak magnitude of a sine wave of current is larger than its rms value by a factor of $\sqrt{2}$. Therefore, the amount of dc current required to produce the same amount of magnetic force as the peak of the indicated ac rms sine wave current must be $\sqrt{2}$ times as large. The abscissa of the ac TCC is uniformly scaled in units of symmetrical rms ac amperes or ac per-unit current. Therefore, a correction to the abscissa current values in the instantaneous trip area, but not in the thermal trip area, must be made for a dc application. This correction is a current magnitude-multiplying factor. But, it is not a variable multiplying factor like those shown in Table 24 for ac applications. The current multiplying factor

for the dc instantaneous trip area is a constant value of, or near to, $\sqrt{2}$ or approximately 1.4. Circuit breaker manufacturers may indicate the value they prefer to be used in a note on the TCC or in application data.

4.42.2 Similarities and differences between ac and dc circuit breaker evaluations

AC circuit breaker evaluation uses calculation of the ratio of circuit reactance to circuit resistance or the ratio X/R to determine an ac fault-current multiplying factor for application. Table 24 lists ac short-circuit current multiplying factors for a set of circuit ratios of X/R . Similarly, dc circuit breaker evaluation uses calculation of the ratio of circuit inductance to circuit resistance, L/R , but a current multiplying factor is not determined from this ratio. With the prospective dc short-circuit current magnitude satisfactory, the L/R ratio is a determining criterion for dc circuit breaker evaluation.

In pure dc circuits where the sources are batteries or constant voltage dc generators, the prospective ultimate short-circuit current is simply E/R , where E is the dc source voltage and R is the dc circuit resistance. Short-circuit current rises exponentially toward this prospective peak at a rate proportional to the L/R time constant. But, where dc power is derived through rectifiers connected to an ac circuit, the ratio of X/R in the ac part of the circuit can affect the dc prospective current magnitude. Transient offset current in the ac part of the circuit can be carried through the rectifier to increase the dc prospective current during the transient period. The dc prospective current in that case also has a transient peak. The net result is that the effect of the X/R ratio of the ac side of the rectifier circuit can affect the magnitude of the dc prospective fault current. The amount of increase and the duration of current offset depend on several factors. If the rectifier is controlled electronically and is very fast, the controller can have an effect on both the dc current magnitude and/or its duration. If the rectifier is not electronically controlled, then the impedance of the rectifier devices can affect the magnitude. If the rectifier solid-state devices are fused, then the fuse characteristics can become a consideration. Therefore, the effect of the ac part of the circuit and the rectifier must be considered to determine the dc prospective current when applying a circuit breaker for rectifier dc applications.

In effect, the L/R ratio, which is the dc circuit time-constant, serves to relate the dc interrupting conditions to the ac interrupting conditions associated with the ac rms sinusoidal current indicated on the abscissa of the ac time-current-curve. It takes into account the difference in current wave shape and clearing energy dissipation. The L/R time-constant has units of seconds, and the limiting values for application are as follows. For application of MCCBs designed per UL 489, which have interrupting current ratings less than 10 000 A, the circuit L/R time-constant must be equal to or less than 3 ms, 0.003 s. For those circuit breakers having rated interrupting currents equal to or greater than 10 000 A, the circuit L/R time-constant must be equal to or less than 8 ms, 0.008 s.

Most thermal-magnetic molded-case circuit breakers blow open under fault conditions. They usually interrupt fast enough to limit the maximum fault current but usually not enough to satisfy the definition of a current-limiting circuit breaker. By virtue of their impedance and blow-open speed of interruption, they never let the prospective current level be reached. (Their rating is based on prospective current, however.) In ac operation, they typically interrupt current flow between a quarter-cycle in time (approximately 4.2 ms at 60 Hz) and a half-cycle in time (approximately 8.3 ms at 60 Hz). The dc time-constant limitation relates the fair wear and tear of contacts and arc chutes associated with the ac interruption to dc interruption. Many of the more common dc circuit breaker applications are in control circuits where the power source is a bank of batteries and a charger. In these circuits, in addition to having the charger also contributing to fault current, the dc circuit time-constant can vary over a wide range, possibly exceeding 8 ms. In those cases, a more specific-purpose circuit breaker is required. Summarizing, for dc application of thermal-magnetic MCCBs within their standard design constraints, the dc voltage and interrupting ratings must be satisfied, and the time-constant of the circuit must satisfy the time-constant constraint for the circuit breaker interrupting current rating. No fault current magnitude-multiplying factor is applied due to the L/R ratio.

4.42.3 DC circuit connections

A very practical aspect of the application of molded-case circuit breakers in dc circuits is the question about how to connect them into the circuit. There are different possibilities for connection for one, two, three, and possibly four-pole circuit breakers.

- a) For single-pole circuit breakers, there is no question. When applicable, one pole interrupts the circuit, and with only that one conductor open, both sides of the load cannot be totally isolated from the source.
- b) With two-pole circuit breakers, one pole in each side of the dc circuit puts two contacts in series for interruption, and when both contacts are open, they isolate both sides of the load totally from the source. With both contacts in one side of the circuit, they, like single-pole circuit breakers, can interrupt fault current, but they will not totally isolate both sides of the circuit from the source when they are open.
- c) Whenever a standard three-pole or possibly a four-pole circuit breaker is used in a dc circuit application, there are the choices of using one, two, three, or all four poles (circuit breaker contacts) in series. UL 489 requires the use of two contacts for two-pole circuit breakers and three contacts for three-pole circuit breakers. Usually, the manufacturer indicates the minimum number of poles required for the voltage and interrupting rating. If only two poles of a three-pole circuit breaker are sufficient for interruption, the connection is like the two-pole circuit breaker case, but the manufacturer may specify which two poles should be used. Whenever three or four poles are to be used in series, a close local connection from one pole of the circuit breaker to another is probably required. Hardware to make the short local connection between poles neat and convenient may be available from the circuit breaker manufacturer. The user should refer to the manufacturer's literature for details on dc application. As arbitrary as the connection might seem, there is a possibility that the manufacturer may want pole currents to be flowing in a given direction through the circuit breaker for magnetic field considerations. It is therefore advisable to check the manufacturer's literature before planning the connection.

4.42.4 Trip unit differences for dc application

Many standard ac thermal-magnetic molded-case circuit breakers lend themselves readily to application in dc circuits. But some of the more recently designed molded-case circuit breakers can use different kinds of trip units. If the trip unit installed in a given molded-case circuit breaker is not a thermal-magnetic trip unit, it may not be suitable at all for use in dc circuits. Therefore, special care must be taken when applying molded-case circuit breakers on dc.

An optionally available ac electronic trip unit will most likely not function properly when subjected to constant dc current, and it should not be expected to respond effectively to transient dc current changes either. Electronic trip units are made specifically for dc circuit breakers. They incorporate special sensors for dc current. Their electronic trip circuits are designed to accept dc signals. Their TCC characteristic shapes are generally very much like those of ac electronic trip units. That is, the trip characteristics will most often be composed of straight-line segments that indicate computed electronic decision making, not thermal or magnetic force responses. Also, the units of measure on the abscissa of their TCCs will be given directly in dc amperes.

5. Specific applications

5.1 Scope

This clause describes the systematic procedures for determining the type, rating, and protective characteristics of low-voltage circuit breakers applied for specific purposes. The three types of circuit breakers are as follows:

- Low-voltage power circuit breakers (LVPCBs)
- Molded-case circuit breakers (MCCBs)
- Insulated-case circuit breakers (ICCBs)

Specific circuit applications discussed in this chapter are as follows:

- Service entrance
- Main circuit breakers
- Tie circuit breakers

5.2 Selection considerations

Selection considerations should include the following:

- a) Compliance with nationally recognized regulations and standards such as NEC (NFPA 70-2011), and those from the Occupational Safety and Health Administration (OSHA), UL, IEEE, and NEMA, where applicable, along with any local codes or safety requirements. In addition, IEEE standards contain useful application information for various types of systems. These standards include IEEE Std 141 (*IEEE Red Book*) [B4] for industrial plants, IEEE Std 241 (*IEEE Gray Book*) [B6] for commercial systems, IEEE Std 242 (*IEEE Buff Book*) [B7] for protection and coordination of electrical systems, IEEE Std 1458 and NEMA AB3.
- b) Special or unusual requirements imposed by characteristics of the electrical power source.
- c) Special or unusual requirements resulting from load characteristics.
- d) Interconnected system performance objectives with respect to selective fault clearing.
- e) Unusual operating conditions.
- f) Special requirements for personnel safety.
- g) Type of equipment in which the circuit breaker is mounted (individual enclosure, panelboard, switchboard, MCC, metal-enclosed switchgear).
- h) Selection of circuit breaker settings that allow for consideration of arc-flash incident energy analysis and mitigation.

It is recognized that the type of facility (e.g., industrial plant, continuous process, commercial building, hospital, etc.), as well as economics, facility operating and maintenance philosophies and capabilities, and standardization programs may influence the selection process described with particular effect on the type of circuit breaker being applied. Such aspects are, by necessity, excluded from consideration in this clause.

Service conditions that differ from those described in Clause 4 of IEEE Std C37.13, Clause 4 of IEEE Std C37.14, and NEMA AB 3 [B14] are beyond the scope of this clause.

5.3 Selection approach for application requirements

This subclause covers the application of standard-purpose low-voltage circuit breakers in specific applications. Special-purpose circuit breaker applications are covered in Clause 6.

5.4 Selection approach for electrical ratings

5.4.1 System voltage

Circuit breakers are rated by voltage class and should be applied only to system voltages within their ratings. System voltage is a determining factor of the circuit breaker interrupting rating. MCCBs have either straight voltage ratings or slash voltage ratings. Refer to 4.12. Circuit breakers with slash voltage ratings, such as 480 Y/277 V or 120/240 V, may be applied only on solidly grounded neutral systems as shown in Figure 7 and Figure 8. Circuit breakers with straight ratings, and all LVPCBs, can be applied on ungrounded as well as on grounded systems.

5.4.2 System grounding

Most circuit breakers are rated for application on low-voltage systems that are solidly grounded wye, high-resistance grounded wye, ungrounded delta, and center-grounded delta. Circuit breakers are also available for corner-grounded delta. A brief description/discussion is provided for each of these various power system configurations, and MCCB requirements are indicated in Figure 9 through Figure 13 as follows:

NOTE—Additional information on ratings and testing that may be useful for these applications is indicated in Clause 4.

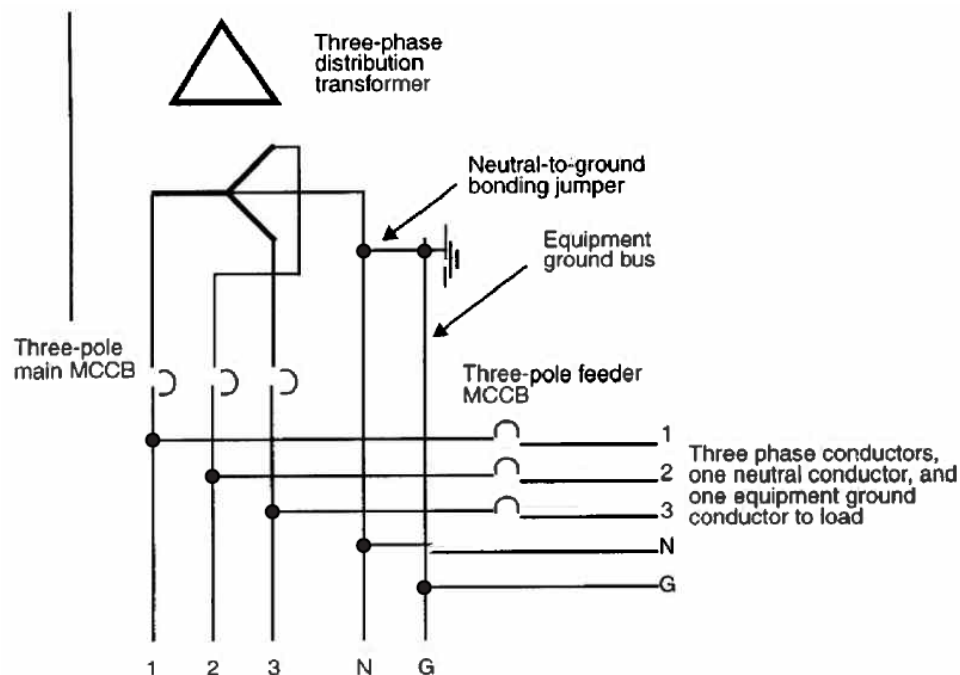


Figure 7—480Y/277 V power system

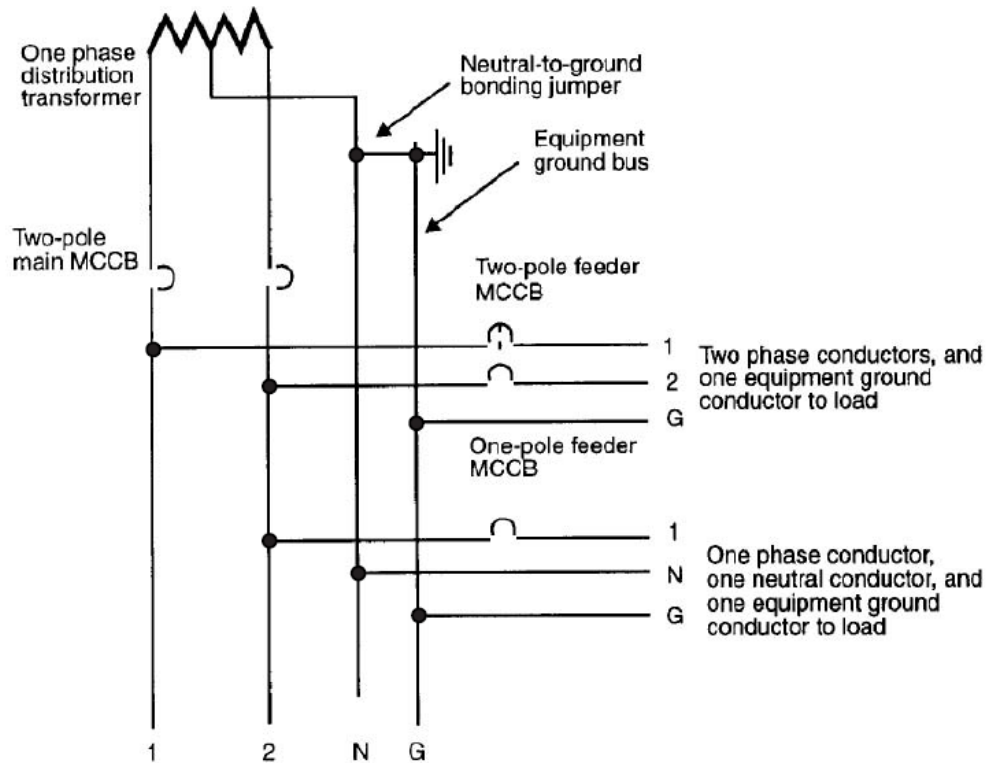
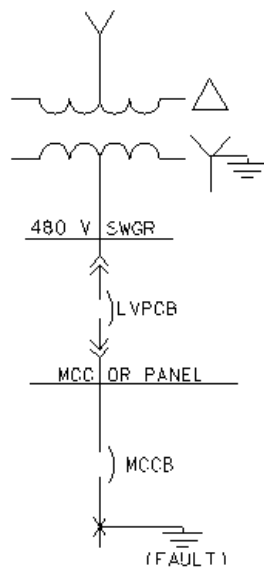
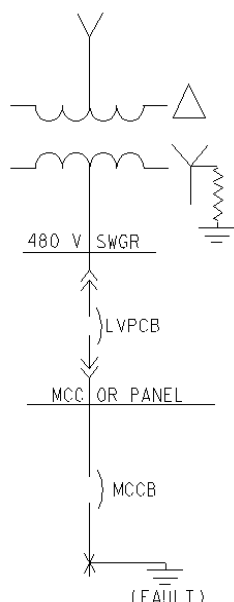


Figure 8—120/240 V power system



This solidly-grounded WYE system is the most common in North America. This system is typically delta-connected on the primary and wye-connected on the secondary with the neutral solidly connected to ground. The grounded neutral conductor carries the single-phase or unbalanced three-phase current. A single line-to-ground or line-to-neutral fault is the kind of fault that would involve an individual circuit breaker pole interruption in this system. For a four-wire 480 Y/277 V system, the voltage across each pole would be limited to 277 V during the time the circuit breaker is interrupting the fault. The individual pole interrupting capability of a MCCB for this system is its marked interrupting rating. In other words, an individual pole of a three-pole MCCB with a 65 kA interrupting rating at 480 V in a 480 Y/277 V system is capable of interrupting a single-phase fault of 65 kA at 277 V, which is 0.577 or 58% of 480 V. This same principle holds for a MCCB connected to a 208 Y/120 V system.

Figure 9—480 Y/277 V or 208 Y/120 V ac solidly grounded systems



The high-resistance grounded wye system is used in process plants as a means to minimize the overall impact of a possible ground fault that may occur on the system. In this case, a resistor is connected between the transformer secondary neutral connection and the ground. The magnitude of the ground resistance is chosen to limit the ground fault current to be equal to or slightly greater than the charging current of the system, thus reducing possible transient overvoltages. This permits plant operations to continue during first ground fault conditions until an appropriate outage can be scheduled to clear the fault. Consideration should be given in using this type of grounding system for a possible second ground fault occurring on another phase before the first fault is cleared, resulting in a phase-to-ground-to-phase fault that is not limited by the neutral grounding resistor. When the second phase-to-ground fault occurs, it is possible to impress full line-to-line voltage across one pole of the MCCB. Many MCCBs are rated 65 kA for application where the available short-circuit current of a three-phase bolted fault is at that level. However, an MCCB with a straight voltage rating and a frame rating between 100 A and 800 A will have an individual pole short-circuit test at 8.7 kA at line-to-line voltage. Only MCCBs with an adequate single-pole rating and a straight voltage rating may be applied in this type of system. Relays are available that will alarm on the first fault and trip on the second fault in time to prevent burn downs. For additional application details concerning high-resistance grounding, please refer to IEEE Std 242 (*IEEE Buff Book*) [B7].

Figure 10—480 Y/277 V ac high-resistance grounded system

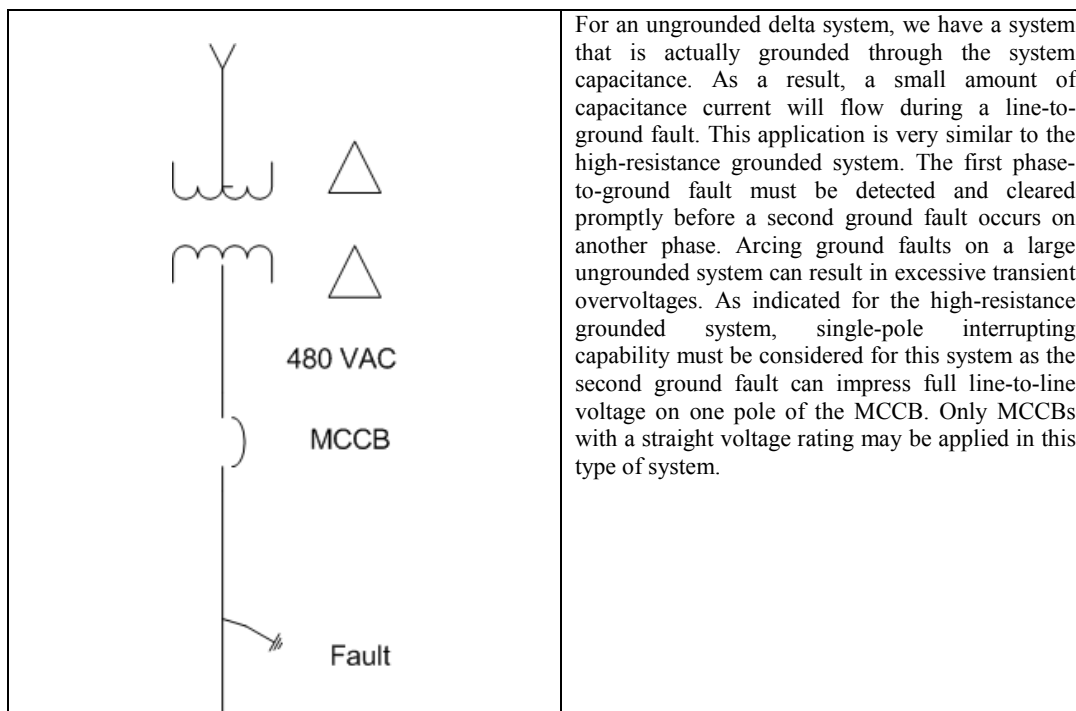


Figure 11—Ungrounded 480 V delta connected system

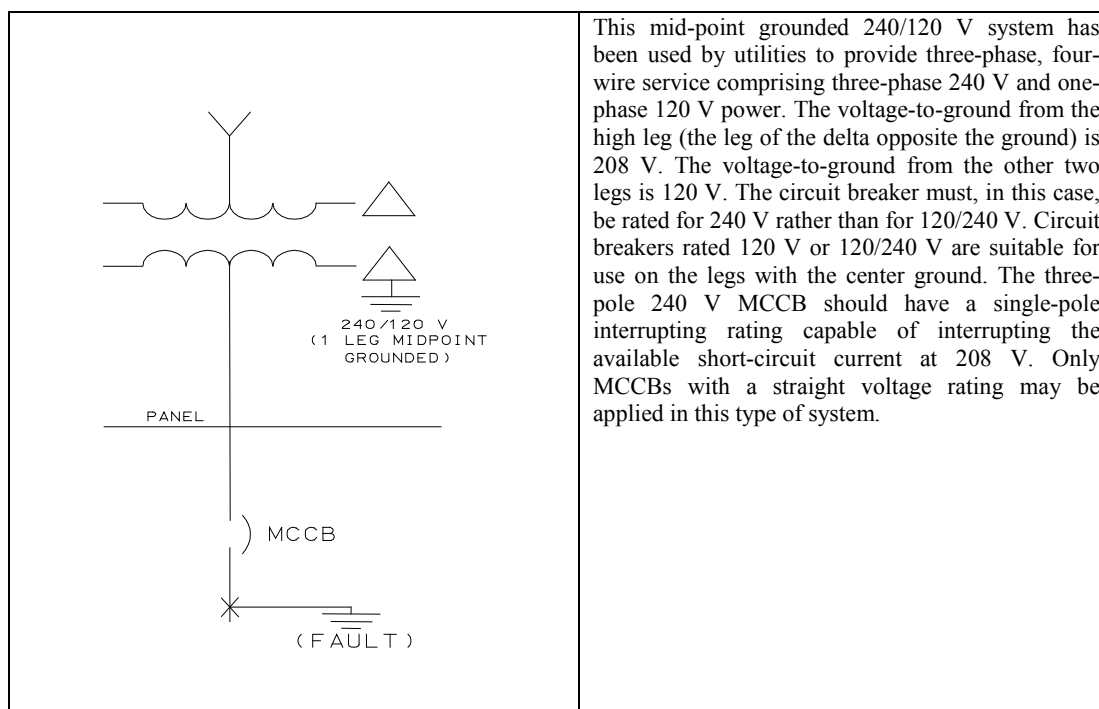


Figure 12—240/120 V ac mid-point grounded system

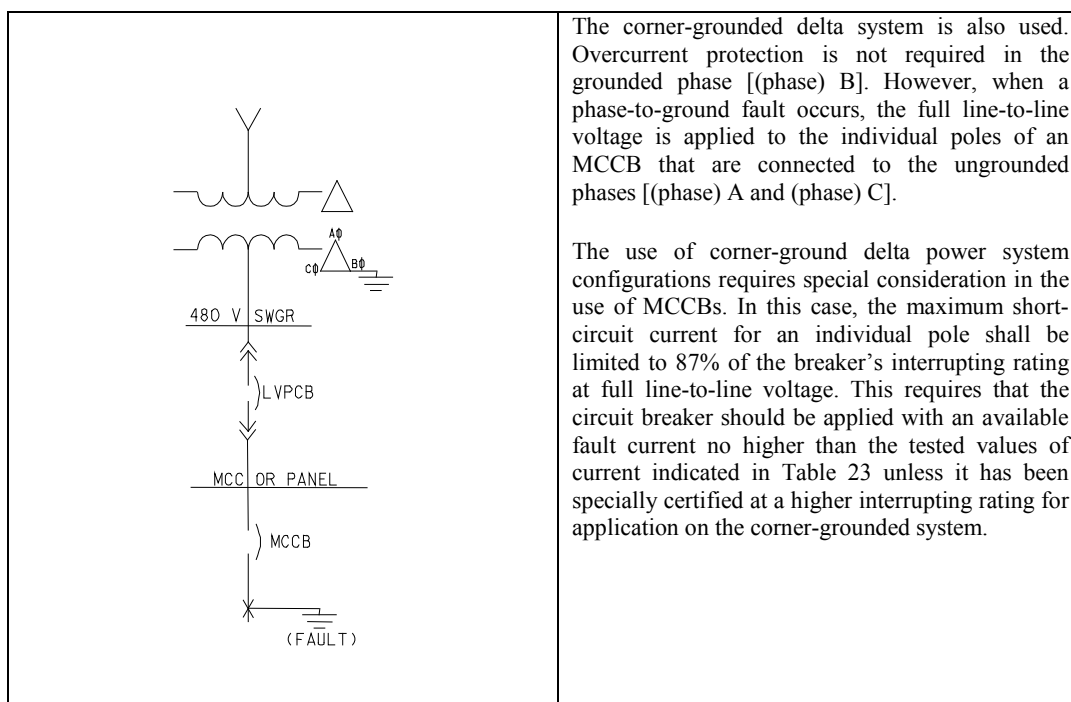


Figure 13—480 V ac corner-grounded delta system

When selecting the type of circuit breaker for use on low-voltage, solidly grounded systems of more than 150 V-to-ground, the use of integral ground-fault trip elements should be considered. Ground-fault tripping is recommended for some applications, and it is required by the NEC for certain service entrance and feeder applications (refer to 230.95, 215.10, and 240.13 of NFPA 70-2011).

Ground-fault trip elements may also be used on high-resistance grounded and ungrounded systems, but they will not operate for the first ground fault. However, if a second ground fault occurs in a different phase in the system, they will provide backup protection, which is more sensitive than the phase elements.

5.4.3 System frequency

Applications on systems other than 60 Hz should be checked with the manufacturer. Refer to 4.13. Systems rated 50 Hz may require special calibration of the trip device.

Circuit breakers with thermal-magnetic trip devices that are directly heated can generally be applied to power systems with a frequency up to 120 Hz without de-rating. Application of these circuit breakers above 120 Hz will result in increased eddy currents and iron losses, which cause greater heating within the thermal trip elements. To avoid this potential problem, the circuit breaker should either be calibrated for the specific frequency, be de-rated accordingly, or both. The amount of de-rating depends on the frame size and current rating as well as the system frequency.

Some thermal-magnetic circuit breakers rated 600 A, and many thermal-magnetic circuit breakers with higher current ratings, have a transformer-heated bimetal and are suitable for 60 Hz maximum. They require special calibration for 50 Hz.

Circuit breakers with electronic trip devices receive their signals from sensors which may have degraded accuracy when operated at frequencies outside of the operating range for which they were designed and calibrated. Consult with manufacturer for application on high harmonic content loads or fundamental frequencies other than 50 Hz or 60 Hz, such as 400 Hz.

5.4.4 Continuous-load current

5.4.4.1 Continuous current rating or setting

The continuous-load current of a circuit determines the minimum conductor size. The trip rating or setting of the circuit breaker should be selected to protect the load and/or conductor. The trip rating or setting of the various types of circuit breakers is established as follows:

- a) Thermal-magnetic trip units of MCCBs may be non-interchangeable. MCCBs containing these trip units are available in many current ratings up to the frame size of the circuit breaker. The circuit breaker rating is the trip rating.
- b) Thermal-magnetic trip devices of ICCBs and LVPCBs may be interchangeable and are available in many current ratings up to the frame size of the circuit breaker. These units may be changed in the field. The trip rating of the circuit breaker depends on the trip unit installed.
- c) Electronic trip units, available on MCCBs, ICCBs, and LVPCBs, use current sensors with ratings equal to or less than the continuous current rating of the circuit breaker. Rating plugs may be used to increase the range of settings. The trip unit provides an adjustable range of settings equal to or less than the sensor or plug rating. The sensor rating, plug rating (if applicable), and current setting selected from the adjustment range (if applicable) determine the trip setting of the circuit breaker.

The load current should not exceed the continuous current rating or setting for 100% rated circuit breakers, which includes all LVPCBs as well as ICCBs and MCCBs that are specifically rated and labeled for 100%. Other ICCBs and MCCBs may be applied at only 80% of the circuit breaker rating for non-interchangeable trip type, 80% of the trip unit rating for interchangeable trip type, or trip setting of adjustable trip type.

5.4.4.2 Ambient temperature and altitude

De-rating of the circuit breaker's continuous current at higher ambient temperatures, humidity, or altitudes than rated conditions should be checked in 4.17 through 4.19.

5.4.4.3 Harmonics

Circuit breakers with trip devices that use rms sensing are most suited to applications where harmonics are known to be a problem. Peak sensing units react to the peak value of the distorted wave shape, which does not correspond to the effective heating value of the current.

5.4.5 Available short-circuit current

5.4.5.1 Reverse fed applications

Circuit breakers may be applied in applications where alternative power solutions are provided placing special demands on the circuit breaker that may impact the selection of the circuit breaker. A circuit breaker in some applications may be subjected to a reverse feed situation. Reverse feed refers to the way the power cables supplying current are connected to the circuit breaker. Most of the time, the installation of a circuit breaker and associated connections is quite simple and straight forward as line and load is very clear. This may not always be the case, though, as the application may automatically re-configure itself to put a circuit breaker into a reverse feed situation. The presence of an alternative source such as a photovoltaic supply on a home or business is a good example of this. The installer must understand how the application functions to best select and apply the equipment for any such configuration.

Only those circuit breakers that are not labeled with the words “line” and “load” can be used in reverse feed applications. The presence of these markings indicates that it should NOT be applied in a reverse feed application. Paragraph 9.1.1.13 of UL 489-2006 notes that, “Circuit breakers shall be marked ‘line’ and ‘load’ unless the construction and the test results are acceptable with the line and load connections reversed. A frame with interchangeable trip units that complies with 6.1.5.12 is not required to be marked ‘line’ and ‘load’.”

All low-voltage power circuit breakers designed to UL 1066 are tested for reverse power feed and can be used in these applications.

5.4.5.2 Interrupting rating

The interrupting rating of a circuit breaker is the highest current at rated voltage that it is intended to interrupt under standard test conditions. Refer to Article 100 from the NEC, and 4.30 of this recommended practice.

The symmetrical interrupting rating of the circuit breaker shall exceed the calculated available short-circuit current at the point of application. The available short-circuit current includes contributions from all utility sources, plant generation, and connected motors. The interrupting rating of the circuit breaker is specific for the voltage at which it is applied. Refer to Table 8 and Table 9 for standard interrupting ratings of the various types of low-voltage circuit breakers at different system voltages. Consult the manufacturers for ratings of specific circuit breakers because some are available with interrupting ratings higher than the minimum rating required by IEEE Std C37.16. A short-circuit study is required to determine the magnitude of three-phase and single-phase short-circuit current at various points in the system. The procedure for performing short-circuit studies is provided in IEEE Std 141 (*IEEE Red Book*) [B4], IEEE Std 241 (*IEEE Gray Book*) [B6], and IEEE Std 242 (*IEEE Buff Book*) [B7]. The calculated symmetrical short-circuit currents should be reviewed with respect to the expected system short-circuit X/R ratio or associated short-circuit power factor because the interrupting rating of the circuit breaker is based on a specific maximum X/R ratio. This is described in 4.40.

To obtain selective coordination over the entire short-circuit current range, LVPCBs may be applied without instantaneous trip elements. When applied without the instantaneous trip element, the interrupting rating is the same as the short-time rating, as shown in Table 9.

LVPCBs may be applied without integral trip units. In such cases, they are generally applied with separate overcurrent relays and tripped using a shunt trip device. In these applications, it is important to use the short-time rating rather than the interrupting rating, as shown in Table 9. The short-time current is defined as the current at a maximum clearing time of 0.5 s at rated short-circuit per Table 42 of IEEE Std C37.17-2012.

When high interrupting ratings and/or current-limiting capabilities are needed, current-limiting MCCBs or integrally fused MCCBs and fused LVPCBs may be used as a design option. Refer to Clause 6.

5.4.5.3 Series-connected ratings

The series-connected rating is a UL-recognized interrupting rating for a combination of line-side and load-side MCCBs. The load-side circuit breaker interrupting rating may be less than the rating of the combination as shown in Figure 14. UL-recognized series combinations of fuses and MCCBs also exist (refer to the UL Recognized Component Directory [B26]).

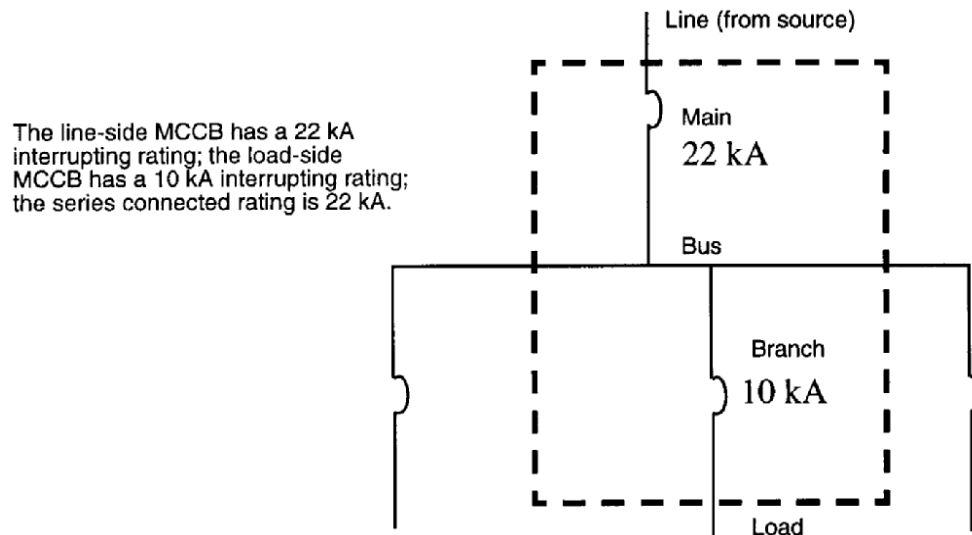


Figure 14—Series-connected rating

Equipment containing MCCBs, such as switchboards, panelboards, and residential service entrance equipment, must be tested and assigned a UL short-circuit rating when based on the rating of the series combination of circuit breakers used (tests may cover other main overcurrent protective devices).

Protective device series ratings are not limited to devices located in the same enclosure, such as panelboard main and branch circuit breakers. They can be located in different equipment, such as a residential metering distribution panelboard circuit breaker and a load-side residential load center, or a line-side switchboard and a load-side panelboard. Equipment will have rating labels that show short-circuit ratings when protected by series-connected rated line-side devices.

The load-side circuit breaker of a series combination must be located in equipment that is listed and marked for use with series-connected ratings that include that circuit breaker.

Series-connected ratings for each manufacturer's equipment using series combinations of MCCBs are established by that manufacturer with testing witnessed by UL or CSA. A series-combination should not use different manufacturers' circuit breakers even though the manufacturers have similar designs because no testing has been done to verify a series-connected rating.

The principal benefit of series ratings is the cost savings realized by using load-side circuit breakers whose interrupting rating is less than the available short-circuit current. However, there are disadvantages. The following should be considered when applying circuit breakers in a series combination:

- a) One disadvantage of series combination is the possible loss of selective coordination at high-fault currents. A fully rated system might be arranged to avoid tripping the main circuit breaker for a feeder short-circuit, but the series combination requires both the main and the feeder circuit breakers to trip when the available short-circuit current is above the instantaneous trip of the main circuit breaker. This is necessary to protect the load-side circuit breaker despite the disadvantage that opening the main circuit breaker interrupts power to all feeder loads that could have continued to operate in a selective system.
- b) Series ratings require certain considerations in their applications that have to be handled by a power systems engineer. The line-side circuit breaker or other device opens to protect the underrated load-side circuit breaker when the short-circuit current exceeds the load-side circuit breaker interrupting rating but is equal to or less than the line-side device rating. Both the line-side device and the load-side circuit breaker may operate in this situation.

- c) Series ratings cannot be applied if large motors, or other equipment that contributes to a short-circuit current, are connected between the line-side MCCB or other device and the load-side MCCB.
- d) To accomplish selectivity, the circuit breakers shall have adjustable trip devices set to operate on the minimum level of short-circuit current. This permits them to be selective while distinguishing between short-circuit current and permissible load-current peaks. The circuit breakers should function in the minimum time possible and still be selective with other overcurrent protective devices in series. When these two requirements are met, the damage to equipment or the inconvenience caused by loss of power will be held to a minimum.
- e) Series-connected ratings may be applicable when lowest first cost is the primary consideration and when selectivity, continuity of service, and lower maintenance costs are secondary considerations. When selectivity and reliability are more important than the first cost, the use of fully rated equipment is recommended.
- f) A portion of a specific manufacturer's UL listing of series-connected ratings for MCCBs is given in Table 25.

Table 25—Representative MCCB series-connected interrupting ratings

Main device			Branch breaker			Interrupting rating rms		
Type	A	Poles	Type	A	Poles	Symmetrical A	V ac	Phase
SKH	300-1200	2,3	TK4V	400-1200	3	65 000	240	1,3
SKH	300-1200	2,3	TJJ	125-400	2,3	65 000	240	1,3
SKH	300-1200	2,3	TJK	125-600	2,3	65 000	240	1,3
SKH	300-1200	2,3	TJ4V	150-600	2,3	65 000	240	1,3
SKH	300-1200	2,3	TFJ, TFK	70-225	2,3	65 000	240	1,3
SKH	300-1200	2,3	TED	110-150	3	65 000	240	1,3
SKH	300-1200	2,3	TFJ, TFK	70-225	2,3	25 000	480	1,3
SKH	300-1200	2,3	TJK	250-600	2,3	35 000	480	1,3
SKH	300-1200	2,3	TJ4V	150-600	3	35 000	480	1,3
SKH	300-1200	2,3	TKM	300-1200	2,3	35 000	480	1,3
SKH	300-1200	2,3	TK4V	400-1200	3	35 000	480	1,3
SKH	300-1200	2,3	TJJ	400	2,3	35 000	480	1,3
SKH	300-1200	2,3	SFH	70-250	2,3	35 000	480	1,3
SKL	300-1200	2,3	SFH	70-250	2,3	100 000	240	1,3
SKL	300-1200	2,3	SFH	70-250	2,3	65 000	480	1,3
SKP	300-1200	2,3	SFH, SFL	70-250	2,3	200 000	240	1,3
SKP	300-1200	2,3	SFH, SFL	70-250	2,3	100 000	480	1,3
SKL	300-1200	2,3	SKH	300-1200	2,3	100 000	240	1,3
SKL	300-1200	2,3	SKH	300-1200	2,3	65 000	480	1,3
SKH	300-1200	3	SFH	70-250	3	25 000	600	1,3
TPV	200-3000	3	SKH	300-1200	2,3	100 000	240	1,3
TB4	125-250	3	SED, SEH, SEL	15-150	2,3	100 000	480	1,3

Table 25—Representative MCCB series-connected interrupting ratings, continued

TJJ	125-600	2,3	SED	15-150	2,3	25 000	480	1,3
THFK	70-225	2,3	SED	15-150	2,3	25 000	480	1,3
THED	110-125	2,3	SED	15-150	2,3	25 000	480	1,3
THLC2	225	2,3	SED, SEH, SEL	15-150	2,3	200 000	480	1,3
THLC2	225	2,3	SED, SEH, SEL, SEP	15-150	2,3	150 000	277	1
THLC2	225	2,3	SED, SEH, SEL, SEP	15-150	2,3	150 000	480	1,3
THLC4	225-400	3	SED, SEH, SEL	15-150	2,3	100 000	480	1,3
THLC4	225-400	3	SED, SEH, SEL	15-150	2,3	200 000	240	1,3
THLC4	225-400	3	SED, SEH, SEL	15-150	2,3	100 000	277	1
THLC4	225-400	3	SED, SEH, SEL, SEP	15-150	2,3	150 000	480	1
TEL	150	3	SED, SEH	15-150	2,3	100 000	240	1,3
TEL	150	3	SED, SEH	15-150	2,3	65 000	480	1,3
THLC4	225-400	3	SED, SEH, SEL	15-150	2,3	200 000	120/ 240	1
TLB4	225-400	3	SED, SEH	15-150	2,3	65 000	480	1,3
TLB4	225-400	3	SED, SEH	15-150	2,3	85 000	240	1,3
TLB4	225-400	3	SED, SEH	15-150	2,3	65 000	277	1
TLB4	225-400	3	SED, SEH	15-150	2,3	85 000	120/ 240	1

NOTE—These ratings are specific to manufacturer, MCCB type, ampere, and voltage ratings.

Source: General Electric

5.4.5.3.1 Example of a fully rated versus a series-connected rated system

The following list discusses the difference between fully rated and series-connected rated systems:

- A fully rated system has an available short-circuit current less than or equal to the short-circuit rating of the lowest rated component in the equipment. As shown in Figure 15, each protective device in a fully rated system is rated to interrupt the available short-circuit current.
- An alternative system uses a UL listed panelboard containing UL recognized series-rated combinations of circuit breakers whose individual short-circuit ratings may be below the available short-circuit current. For example, if it can be shown by test that a main circuit breaker with a 22 kA interrupting rating and a branch circuit breaker with a 10 kA interrupting rating will interrupt a 22 kA fault (see Figure 14), then the combination is series rated for 22 kA.
- In the example series-connected rated system (see Figure 16), the combination of a 1600 A main circuit breaker with an ampere interrupting rating (AIR) of 85 kA connected in series with either a 225 A circuit breaker with 25 k AIR or a 600 A circuit breaker with 42 k AIR has been tested and assigned a series-connected rating of 65 kA, which is less than the main circuit breaker rating, but more than the rating of the feeder circuit breakers.
- Regardless of whether the protective devices are fully rated or series rated, the bus bracing of the equipment must be equal to or exceed the available short-circuit current of the system as shown in Figure 15 and Figure 16. An exception is when the line-side device is current limiting and tests have demonstrated a higher rating for the bus in series with the current-limiting device.

An example of a fully-rated system on a 208 Y/120 V circuit with 50 kA symmetrical rms available; 1600 A main rated 85 kA AIR connected to two 225 A and two 600 A breakers, all 65 kA AIR.

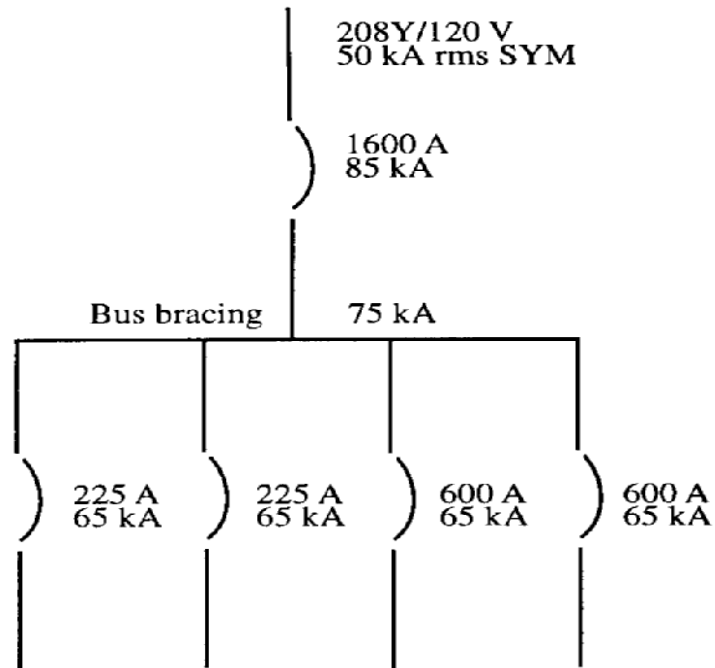


Figure 15—Fully rated system

Combinations of a 1600 A main circuit breaker with 225 A or 600 A feeder circuit breakers have been tested and assigned a series-connected rating of 65 kA AIR. Equipment short-circuit rating is 65 kA.

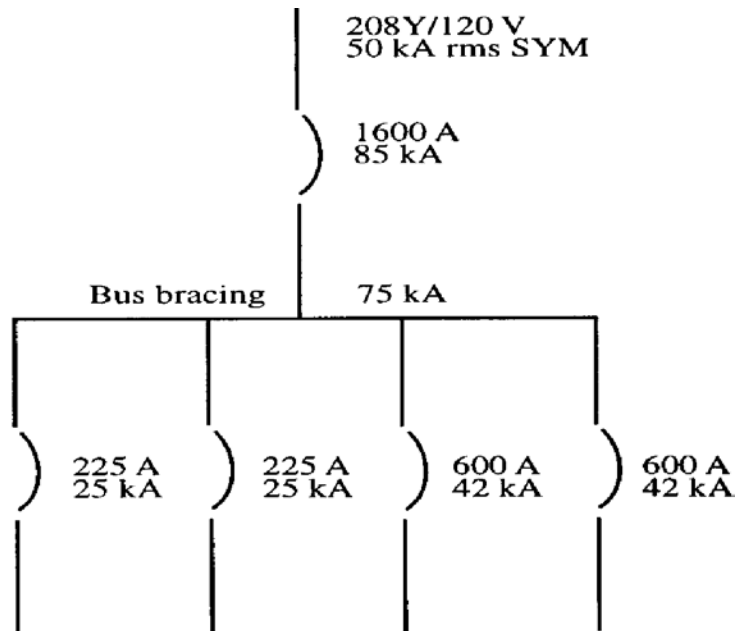


Figure 16—Series-connected rated system

5.4.6 Arcing ground-fault protection for solidly grounded systems

In solidly grounded systems, the arcing line-to-ground fault current is normally considerably lower than the value of a three-phase bolted fault. For example, in a 480Y/277 V system, the arcing fault level can be as low as 38% of the three-phase value. Such arcing faults, because of their destructive nature, must be removed as quickly as possible. Unfortunately, the magnitude of this current may be so low that low-voltage circuit breaker long-time-delay characteristics allow it to persist too long.

As it is the circuit impedance that limits the current flowing in an arcing fault, an equipment bonding (grounding) conductor is often included with the phase conductors, to provide a lower reactance ground path. The resulting higher ground-fault current is more readily detected and removed in a shorter period of time.

The best protection against this type of fault is to select a trip unit with a ground trip function. (A more thorough discussion of this problem is given in Chapter 8 of IEEE Std 242-2001 (*IEEE Buff Book*) [B7].) A ground-fault trip function may be required (refer to section 230.95, section 240.13, and section 215.10 of the NEC).

5.5 Modifications and accessories for specific applications

Some modifications and accessories for low-voltage circuit breakers are available in kit form for field installation. However, many are available factory-installed and cannot be added later in the field.

5.5.1 Shunt trip device

A shunt trip is used to electrically trip a circuit breaker, manually or automatically, through a contact or switch located remotely from the breaker. The shunt trip circuit must be energized by some ac or dc control power source. The shunt trip device can be used for tripping from a separate protective relay, or for local or remote control.

When used for tripping from a protective relay:

- a) A reliable control power source should be used. It may be a station battery or an uninterruptible power supply (UPS). If ac must be used, then it is necessary to also provide a capacitor trip device for each shunt trip device.
- b) The short-time short-circuit rating of the circuit breaker shall exceed the available short-circuit current at the point of application.

When used for control purposes, the reliability of the control power source depends on the application. When used for remote control, the shunt trip device may be powered from the remote source; but in this case, special care must be given to assure that the voltage of the shunt trip device is within the range of the supplied control voltage.

5.5.2 Undervoltage release

An undervoltage release trips the circuit breaker whenever the voltage being monitored falls below a predetermined level. They are available with either time delay or instantaneous operation. The two types of undervoltage releases available are as follows:

- a) *Electromechanical automatic reset used in combination with undervoltage release.* When the voltage falls below a predetermined level, a solenoid mechanism will initiate tripping of the circuit breaker. The circuit breaker cannot be closed until the voltage returns to approximately 85% of normal.
- b) *Handle reset.* The handle reset undervoltage release spring is cocked or precharged through the circuit breaker handle mechanism. The major advantage of this type is that the circuit breaker mechanism cannot be latched when there is no power on the undervoltage release coil. It prevents circuit breaker mechanism damage due to repeated attempts to close the circuit breaker with a de-energized undervoltage release coil.

NOTE—One design consideration for the use of both types of undervoltage release, as indicated above, is that they do not depend on control power to trip the circuit breaker.

The undervoltage release can be used to open the circuit breaker during a system undervoltage condition, in applications such as motor protection for cases where a magnetic contactor is not available to drop out, or where a sequenced restart is desired as opposed to full start-up of all devices and loads when power is restored.

5.5.3 Auxiliary switches

An auxiliary switch consists of normally open or normally closed contacts mounted in the circuit breaker that change state whenever the circuit breaker is opened or closed. To avoid confusion, the contacts are defined as *a* contacts that are open when the circuit breaker is open or tripped, and *b* contacts that are closed when the circuit breaker is open. The specifications of the manufacturer should be consulted for the position of these auxiliary switch contacts when the circuit breaker is in the tripped position.

Auxiliary switches may be used with an indicating device to show the position of the circuit breaker and are used in the control circuit for interlocking purposes.

For more information, see 4.5.3 of IEEE Std C37.2™-2008 [B12].

5.5.4 Mechanism operated cell (MOC) switch

Used with drawout circuit breakers, MOC switches are similar to auxiliary switches, except that they are mounted within a cubicle and are operated mechanically by the circuit breaker mechanism. The *a* and *b* designations are the same as on auxiliary switches. They can be set to function in both the test and connect or the connect-only position. They are used when more auxiliary contacts are required than are available on the circuit breaker.

For more information, see 4.5.3 of IEEE Std C37.2-2008 [B12].

5.5.5 Truck operated cell (TOC) switches, cell switches, or position switches

Used with drawout circuit breakers, TOC switches change state when the circuit breaker is moved between the connected (operating) position and the test or disconnected position. A normally open contact is open when the breaker is *not* in the connected position. A normally closed contact is closed when the circuit breaker is *not* in the operating position. The TOC switch may be used with an indicating device to show the position of the circuit breaker, or in the control circuit to prevent operation of the circuit breaker in one of its positions.

For more information, see 4.5.3 of IEEE Std C37.2-2008 [B12].

5.5.6 Alarm switches

Alarm switches, sometimes referred to as bell alarm contacts, differ from auxiliary switches in that they function only when the circuit breaker trips automatically, not with the manual opening of the circuit breaker.

An alarm switch consists of a contact or set of contacts (NO or NC) which change state when the circuit breaker is tripped by the trip unit or an auxiliary trip device. The contacts remain in this changed state until reset electrically or mechanically at the circuit breaker. The contacts can be used to simply indicate that the circuit breaker has tripped or in a control circuit to prevent its own reclosing or the closing of another circuit breaker.

5.5.7 Motor operators on MCCBs

The motor operator, once it is activated by the remote push button or pilot device, will cause the circuit breaker to open or close. A motorized mechanism moves the MCCB handle from the tripped position to the closed position. This type of operation allows remote control of a circuit breaker. However, it is slow compared with the electrical close mechanisms on LVPCBs and ICCBs and may not be fast enough for applications such as synchronizing circuits.

5.5.8 Electrical close mechanism on LVPCBs and ICCBs

An electrical close mechanism consists of a stored energy closing mechanism, spring charging motor, and solenoid release. It includes anti-pump circuitry to prevent cycling. When the spring charging circuit is energized, the springs are charged. Once charged, operation of a remote push button, switch, or pilot device operates a solenoid that releases the springs, thus allowing the circuit breaker to close. After the circuit breaker is closed, the springs are recharged for the next trip-close-trip cycle of operations.

5.5.9 Mechanical interlocks

There are several methods of mechanically interlocking circuit breakers. These methods are walking beam, sliding bar, and key interlock. Each method results in the interlocking of two breakers so that only one may be closed (ON) at the same time, yet both may be open (OFF) simultaneously. The type of interlock that may be used depends on the circuit breaker and the equipment in which it is mounted.

5.5.10 Moisture, fungus, and corrosion treatment

For an environment having high moisture content or where fungus growth is prevalent, a special tropical treatment should be specified for the circuit breakers.

NOTE—Circuit breakers should not be exposed to corrosive environments. If there is no alternative, specially treated circuit breakers that are resistant to corrosive environments should be specified.

5.5.11 Terminal shields

Terminal shields protect personnel from accidental contact with energized current-carrying parts.

5.5.12 Handle locks

Handle locks are available to prevent accidental or deliberate manual operation of the circuit breaker. The lock does not prevent opening of the circuit breaker by its trip device.

5.5.13 Handle ties

Handle ties are used to connect two or more circuit breaker handles together to enable manual operation of all poles simultaneously. The handle tie does not prevent opening of the circuit breaker by its trip device.

5.5.14 Shutters

Shutters are used to isolate the primary contacts from source voltage when the circuit breaker is withdrawn. They are not circuit breaker accessories but are used in equipment with circuit breakers. Shutters may be part of the cassette mechanism or equipment structure in drawout circuit breaker installations. Shutters are not applied with bolted circuit breakers, though equipment provided with space for future circuit breakers may use insulating covers to isolate live primary side conductors while the space does not have a circuit breaker installed.

5.6 Normal versus abnormal conditions

Normal environmental and operating conditions are as follows:

- Ambient temperature between -5°C and 40°C
- Altitude does not exceed 2000 m (6600 ft)
- Frequency of 60 Hz

Abnormal environmental and operating conditions that should be considered are as follows:

- Operation at ambient temperatures below -5°C or above 40°C
- Operation at altitudes above 2000 m (6600 ft)
- Exposure to corrosive materials
- Exposure to explosive fumes or dust
- Exposure to dust or moisture
- Abnormal vibrations
- Unusual operating duties
- Harmonics
- Repetitive duty cycle, which results in several operations in a short period of time on a regular basis
- Capacitor bank switching
- Frequent switching
- Circuits with high X/R ratios
- Single-pole interruption with three-pole circuit breakers
- Frequencies other than 60 Hz
- Occurrence of frequent and/or severe faults

5.7 Considerations for applying MCCBs, ICCBs, and LVPCBs

Certain significant design, construction, or testing differences between low-voltage circuit breaker types may determine the choice of circuit breaker type to be selected. ICCBs are considered to be a type of MCCB and are tested in accordance with MCCB standards unless specifically stated otherwise by the manufacturer. However, ICCBs do have some of the features of LVPCBs. Refer to Table 26 for a comparison of circuit breaker features. Table 26 can be helpful in the selection process.

Table 26—Comparison of features

LVPCB	ICCB	MCCB
Selective trip over full range of fault currents up to interrupting rating.	Selective trip over partial range of fault currents within interrupting rating.	Selective trip over a smaller range of fault currents within interrupting rating.
Type of operators: mechanically operated, two-step stored energy, and electrical two-step stored energy.	Types of operators: mechanically operated, two-step stored energy, and electrical two-step stored energy.	Type of operators: mechanically operated over-center toggle or motor operator.
Available in drawout construction permitting racking to a distinct test position and removal for maintenance.	Available in drawout construction permitting racking to a distinct test position and removal for maintenance.	Some are available in plug-in design allowing removal for inspection and maintenance. Large frame sizes may be available in drawout construction.
Operation counter is available.	Operation counter is available.	Operation counter is available.
Interrupting duty at 480 V ac: 22 kA-130 kA without fuses and up to 200 kA (may require fuses).	Interrupting duty at 480 V ac: 22 kA-150 kA.	Interrupting duty at 480 V ac: 22 kA-65 kA without fuses and up to 200 kA with integral fuses or for current-limiting type.
Current limiting available only with fuses.	Current limiting not available.	Current limiting available with and without fuses.
Usually most costly.	Usually mid-range cost, but depends on the enclosure selected.	Usually least costly.
Small number of frame sizes available.	Small number of frame sizes available.	Large number of frame sizes available.
Extensive maintenance may be possible on all frame sizes.	Limited maintenance possible on larger frame sizes.	Limited maintenance possible on larger frame sizes.
Used in enclosures, switchgear, and switchboards.	Used in enclosures and switchboards.	Used in enclosures, panelboards, and switchboards.
Not available in series ratings.	Not available in series ratings.	Available in series ratings.
100% continuous current rated in its enclosure.	80% continuous current rated, unless specifically stated to be rated 100% in an enclosure.	80% continuous current rated, unless specifically stated to be rated 100% in an enclosure.
IEEE Std C37.13	UL 489	UL 489

5.8 Service requirements and protection

Article 230, Part VI and Part VII, from the NEC contain the many requirements for service disconnects of 600 V or less systems (i.e., permissible number of disconnects, sizing, rating of disconnects, overcurrent protection for ungrounded and grounded conductors, location, and ground-fault protection requirements).

5.9 Main circuit breakers

The main circuit breaker, as shown in Figure 17, is used for switching, servicing, and protecting the main bus of an assembly of low-voltage equipment, such as a lineup of switchgear, or a switchboard, panelboard, or MCC. It is often an integral part of the assembly but can be separately located from the distribution assembly, if desired. When part of a service entrance, it is the service disconnecting means, as defined in

the NEC. When the circuit breaker is located in the secondary of a step-down transformer, it serves as the transformer secondary main circuit breaker and should be located as close to the transformer terminals as possible. A main circuit breaker is not always mandatory, but the advantages it provides should be considered.

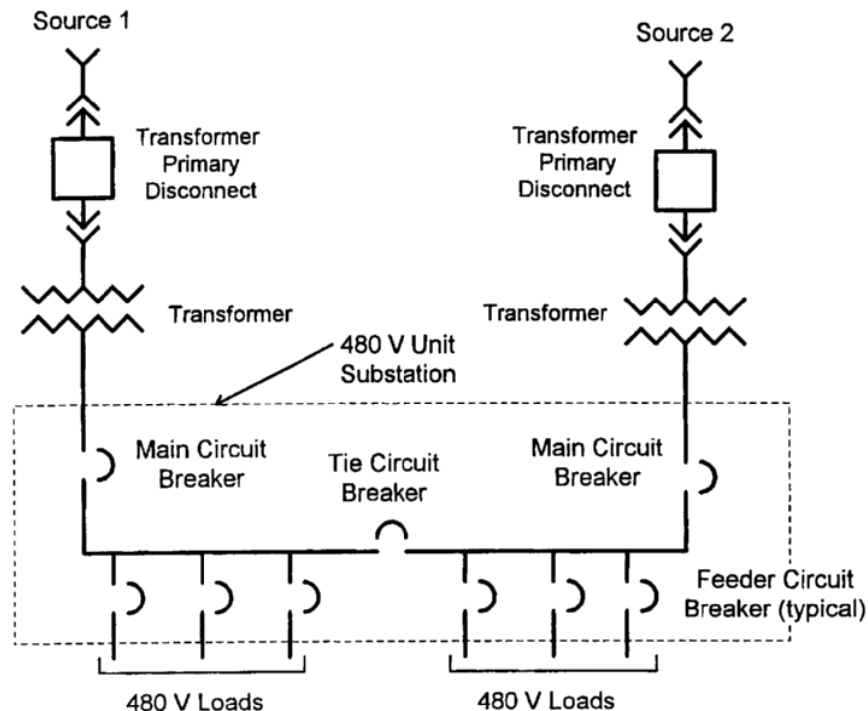


Figure 17—Typical double-ended unit substation

5.9.1 Disconnecting means

Opening the main circuit breaker isolates the load from the power source. It is used to de-energize the system and is very useful when it is necessary to quickly turn OFF the power, such as when a fire occurs in the facility. For this reason, it is mandatory in a service entrance application if the service has more than six feeders or branches. It is useful during maintenance of the equipment to safely lockout/tag out everything downstream when inspecting and maintaining the main bus and connections. The main breaker is also useful for reenergizing the system in an orderly fashion.

5.9.2 Protection device

5.9.2.1 Overload protection

The main circuit breaker provides overload protection for the main bus of the distribution equipment as well as for the incoming power conductors to the circuit breaker. If applied at the transformer secondary, the main circuit breaker provides overload protection for that transformer. The main circuit breaker normally provides better overload protection than the transformer primary protective device. The primary device has a higher current rating or setting to prevent the device from tripping on transformer inrush current during transformer energization.

5.9.2.2 Short-circuit protection

The main circuit breaker provides short-circuit (fault) protection for the conductors (cable and/or bus) between the main circuit breaker and the branch or feeder circuit breakers. For example, it provides short-circuit protection for the main bus in the assembly as well as for the tap-offs to the branch or feeder devices. It also provides backup protection for an uncleared feeder fault.

5.9.2.3 Ground-fault protection

This optional protection is desirable for the main circuit breaker on solidly grounded systems of more than 150 V to ground because of the possibility of low-magnitude arcing ground faults in equipment. Additional ground-fault detection and protection may also be recommended to minimize the damage caused by low current arcing ground faults in other circuits and equipment. However, it should be recognized that ground-fault protection can make coordination of protection more difficult to achieve. When implementing multiple levels of ground-fault protection, coordination considerations should be taken into account, particularly if ground-fault protection is applied in small circuits. Ground-fault protection may be required by the NEC (refer to Article 100 and Section 230.95 and Section 240.13). Multiple levels of ground-fault protection are required in the NEC for hospital applications (refer to Section 517.17).

5.9.2.4 General application considerations

General application considerations for the main circuit breaker are as follows:

- a) The preferred trip functions for selective trip are long-time and short-time (and ground fault, if required). For coordination purposes, instantaneous should be provided only if necessitated by the circuit breaker interrupting rating.
- b) May require key interlocking with a high-voltage switch on the transformer primary.
- c) May require key or electrical interlocking with a tie circuit breaker.

5.10 Tie circuit breakers

The tie circuit breaker, as indicated in Figure 17, is used for switching, servicing, and protecting the main bus of an assembly of low-voltage equipment, such as a line-up of switchgear, or a switchboard, panelboard, or MCC. It is often an integral part of the assembly but can be separately located from the distribution assembly, if desired. It is also used for sectionalizing or isolating a section of bus and to allow for maintenance of the main circuit breaker or transformer. A tie circuit breaker is never mandatory, but the advantages it provides should be considered. The functions performed by the tie circuit breaker include those described in 5.10.1 and 5.10.2.

5.10.1 Disconnecting means

Opening the tie circuit breaker along with one of the main circuit breakers isolates the included bus section from the power source. The tie circuit breaker is used to de-energize a portion of a system and is useful when it is necessary to quickly turn OFF the power. Opening one main circuit breaker and closing the tie circuit breaker enables the system to remain energized while the main circuit breaker or transformer is being maintained. It is useful during maintenance of the equipment to safely lockout/tag out everything downstream when inspecting and maintaining the main bus and connections. The tie circuit breaker is also useful for re-energizing the system in an orderly fashion.

5.10.2 Protection device

5.10.2.1 Overload protection

The tie circuit breaker provides overload protection for a portion of the main bus of the distribution equipment as well as for the upstream power conductors.

5.10.2.2 Short-circuit protection

The tie circuit breaker provides short-circuit (fault) protection for the conductors between the tie circuit breaker and the branch or feeder circuit breakers on that portion of the bus. For example, it provides short-circuit protection for the main bus in the assembly as well as for the tap-offs to the branch or feeder devices. It also provides backup protection for an uncleared feeder fault.

5.10.2.3 Ground-fault protection

This optional protection may be used for the tie circuit breaker on solidly grounded systems of more than 150 V to ground because of the possibility of low-magnitude arcing ground faults that can occur in the main bus bars, which may not be insulated. This may limit the number of feeders that are de-energized in a fault condition (refer to 5.4.6). A ground-fault trip function may be selected to provide ground-fault coordination with the main and feeder circuit breakers. Consideration should be taken of fault probability, systems reliability required, and system selectivity achieved. Ground-fault protection can complicate coordination to achieve selective operation and tie circuit breakers may be closed very rarely. Insulated and isolated buses in modern switchgear may reduce the likelihood of internal arcing ground faults. Overall system reliability and protection should be considered by the responsible power systems engineer.

5.10.2.4 Arc flash hazard mitigation

Circuit breakers that are counted upon to provide arc flash incident energy mitigation should be selected carefully. The operation of the circuit breaker during an arc flash event will depend on the current flowing through the circuit breaker. It is important that selection of the circuit breaker and its protective settings be made with an understanding of the arcing currents expected per IEEE Std 1584™ and good engineering practice.

Circuit breaker settings are often coordinated to achieve optimal selectivity. This may require desensitizing trips or slowing response, or both. These actions may negatively impact arc flash protection. However, understanding the device's selective capabilities and how they can be optimized to achieve the best possible sensitivity and speed may allow circuit breakers to operate rapidly and remain sufficiently selective. Manufacturers provide tools and analytical methods that may allow better settings and better protection than traditional selectivity methods may yield. If adequate protection and selectivity cannot be achieved, contact the circuit breaker's manufacturer to explore options and alternatives.

Optimizing selectivity and arc flash protection is best achieved at the time that devices are selected and circuits are designed. Expecting optimal results based only on the recommendations of a coordination study after devices are installed may not yield desired results.

5.10.2.5 General application considerations

General application considerations for the circuit breaker are as follows:

- a) The preferred trip functions for selective trip are long-time and short-time (and ground fault, if required or if desired, for coordination). For coordination purposes, instantaneous trip functions should be provided only if necessitated by the circuit breaker interrupting rating.
- b) May require key or electrical interlocking with main breakers to prevent paralleling or synchronism check equipment to monitor paralleling.
- c) The preferred trip functions for selective trip are long-time and short-time (and ground fault, if required or if desired, for coordination). Although instantaneous protection can make coordination difficult, it should be considered for the protection of conductors in branch and feeder circuits. It may be required by some circuit breakers for self-protection as well. Manufacturers offer different types of instantaneous protection with varying selectivity capabilities. In difficult applications, manufacturers may be consulted to optimize use of instantaneous protection while achieving desired selectivity.
- d) On four-wire multisource systems, ground-fault protection is complex and requires careful consideration.

6. Fused and special-purpose circuit breakers

6.1 Introduction

This clause covers application considerations for fused circuit breakers and selected special-purpose circuit breakers. These are circuit breakers other than conventional MCCBs or LVPCBs. The clause acknowledges that a wide variety of special circuit breaker products exists, and that those selected here do not comprise the complete selection of special-purpose circuit breakers and their derivatives.

The following circuit breakers and their derivatives will be discussed:

- Instantaneous-trip circuit breakers
- Mine-duty circuit breakers
- Current-limiting circuit breakers
- Molded-case switches
- Fused circuit breakers
- Circuit breaker and ground-fault circuit interrupters
- Circuit breaker and arc fault circuit interrupters
- Supplementary protectors

6.2 Instantaneous-trip circuit breakers

Instantaneous-trip circuit breakers (motor circuit protectors) provide adjustable short-circuit protection but no overload protection. As external overload protection must be used with these breakers, they cannot be used for branch circuit protection. These breakers are primarily used as components in motor circuits in combination with motor starters to provide the short-circuit protection function. They may also serve as the motor disconnecting means. The most typical applications are in motor control centers or individual combination motor controllers or combination motor starters. They are also used in welding equipment for short-circuit protection only. Figure 18 shows typical instantaneous-trip circuit breakers.

6.2.1 Ratings

Instantaneous-trip circuit breakers have a maximum continuous current-carrying capacity. Prolonged continuous currents exceeding this rating may cause damage to the circuit breaker due to overheating.

Instantaneous-trip circuit breakers do not carry an interrupting rating by themselves under industry standards. Instantaneous-trip circuit breakers are most often applied in conjunction with motor controllers. Combination controllers are short-circuit tested with the starter and instantaneous-trip circuit breaker installed. The short-circuit rating that is applied is marked on the combination controller as a result of this test.

UL component recognized breakers are short-circuit tested by themselves at limited available (standard) levels as a basic requirement even though they do not carry an interrupting rating.



Source: Schneider Electric

Figure 18—Example of instantaneous-trip circuit breakers

6.2.2 Current-limiting attachments

Several manufacturers have add-on current-limiting attachments that, if added to the load-side of the instantaneous-trip circuit breaker, will significantly raise the short-circuit withstand current rating of the combination motor starter. Current-limiting attachments contain specially designed fuses that open and limit the current that flows under high-level fault conditions. Low-level fault currents will be interrupted by the instantaneous-trip circuit breaker without opening the current-limiting attachment fuses. High-level

fault currents are interrupted by both the current-limiting module and the circuit breaker. The current-limiting attachment must be replaced after interrupting.

6.2.3 Code considerations

Section 430.52(C)(3) Rating or Setting for Individual Motor Circuit of the NEC-2011 states that:

An instantaneous-trip circuit breaker shall be used only if adjustable and if part of a listed combination motor controller having coordinated motor overload and short-circuit and ground-fault protection in each conductor, and the setting is adjusted to no more than the value specified in Table 430.52.

Informational Note: For the purpose of this article, instantaneous-trip circuit breakers may include a damping means to accommodate a transient motor inrush current without nuisance tripping of the circuit breaker.

Exception No. 1: Where the setting specified in Table 430.52 is not sufficient for the starting current of the motor, the setting of an instantaneous-trip circuit breaker shall be permitted to be increased but shall in no case exceed 1300 percent of the motor full-load current for other than Design B energy efficient motors and no more than 1700 percent of full-load motor current for Design B energy efficient motors. Trip settings above 800 percent for other than Design B energy efficient motors and above 1100 percent for Design B energy efficient motors shall be permitted where the need has been demonstrated by engineering evaluation. In such cases, it shall not be necessary to first apply an instantaneous-trip circuit breaker at 800 percent or 1100 percent.

Exception No. 2: Where the motor full-load current is 8 amperes or less, the setting of the instantaneous-trip circuit breaker with a continuous current rating of 15 amperes or less in a listed combination motor controller that provides coordinated motor branch-circuit overload and short-circuit and ground-fault protection shall be permitted to be increased to the value marked on the controller.

Table 430.52 of the NEC identifies the maximum rating or setting of the instantaneous-trip circuit breaker as 800% for motors other than Design B energy efficient motors and as 1100% for Design B energy efficient motors other than the above exceptions.

6.2.4 Setting of instantaneous-trip circuit breakers

When used in a combination controller, the overload relays provide time delay for starting as well as overcurrent protection up to the locked rotor motor current range. By setting the instantaneous-trip circuit breaker trip level just above the motor starting current, maximum protection can be achieved without nuisance tripping on startup. Most manufacturers publish recommended continuous current ratings and instantaneous-trip ranges for commonly available motors.

When the motor *is* available to the engineer, starting current can be estimated by taking the motor code from its nameplate and using the code letter to estimate locked rotor current from Table 430.7(B) of the NEC.

When the motor is *not* available, locked rotor current can be estimated by using Table 430.251 (A) or (B) of the NEC.

6.3 Mine-duty circuit breakers

Mine-duty circuit breakers are specifically designed for mining duty applications and permit the user to comply with mandatory mining standards. The normal operation of self-propelled mining equipment subjects its trailing cable to extreme and frequent flexing, twisting, and crushing. As a result, electrical faults in trailing cables occur much more frequently than on wiring in normal, stationary installations. Additionally, the presence of loose coal dust and other combustible materials makes the occurrence of such faults hazardous. For these reasons, adequate trailing cable protection is extremely important.

Mine-duty circuit breakers typically have additional safeguards such as adjustable instantaneous-trip settings with tighter tolerances, dust shields and gaskets, non-moisture-absorbing materials, heavy-duty operating mechanisms, heavy-duty undervoltage releases with an external push button, and corrosion-resistant nameplates. Mine-duty circuit breakers are available with voltage ratings up to 1000 V ac and 300 V dc.

6.3.1 Instantaneous-trip setting

The Mine Safety Health Administration (MSHA) CFR, Title 30, Section 75.601, Part 75 indicates that:

Circuit breakers providing short-circuit protection for trailing cables shall be set so as to not exceed the maximum allowable instantaneous settings specified in this section; however, higher settings may be permitted by an authorized representative of the Secretary when he has determined that special applications are justified.

Mine-duty circuit breakers offer adjustable instantaneous-trip settings, or at least several settings that comply with the required maximum allowable trip settings in Table 27.

Table 27 —Maximum allowable circuit breaker instantaneous setting

Conductor size (AWG or kcmil)	Setting (A)
14	50
12	75
10	150
8	200
6	300
4	500
3	600
2	800
1	1000
1/0	1250
2/0	1500
3/0	2000
4/0	2500
250	2500
300	2500
350	2500
400	2500
450	2500
500	2500

Source: Chapter 1, Section 75.601-1 of MSHA CFR, Title 30

6.3.2 Testing requirements

Section The Mine Safety Health Administration (MSHA) 75.900-2, Part 75, CFR, Title 30, states that:

Circuit breakers protecting low- and medium-voltage alternating current circuits serving three phase alternating current equipment and their auxiliary devices shall be tested and examined at least once each month by a person qualified as provided in 75.153. In performing such tests, actuating any of the circuit breaker auxiliaries or control circuits in any manner which causes the circuit breaker to open, shall be considered a proper test. All components of the circuit breaker and its auxiliary devices shall be visually examined and such repairs or adjustments as are indicated by such tests and examinations shall be carried out immediately.

6.3.3 Circuit breaker location

MCCBs used to protect underground circuits are required to be located in areas that are accessible for inspection and testing and have a safe roof.

6.3.4 Additional application requirements

Mine-duty circuit breakers feeding three-phase ac circuits are required to be equipped with devices to provide protection against undervoltage, grounded phase, short-circuits, and overcurrent.

Frequently, mine-duty circuit breakers are specified to be equipped with an undervoltage release. The undervoltage release can serve the following three different purposes:

- a) To trip the circuit breaker during an undervoltage or power outage condition
- b) To provide a tripping mechanism that can be used with ground-fault or interlock circuits
- c) To provide an emergency tripping device that can be activated by a remote switch or push-button

6.4 Current-limiting circuit breakers

UL 489-2013 defines a current-limiting circuit breaker as follows:

A circuit breaker that does not employ a fusible element and that when operating within its current limiting range, limits the let-through I^2t to a value less than the I^2t of a 1/2 cycle wave of the symmetrical prospective current.

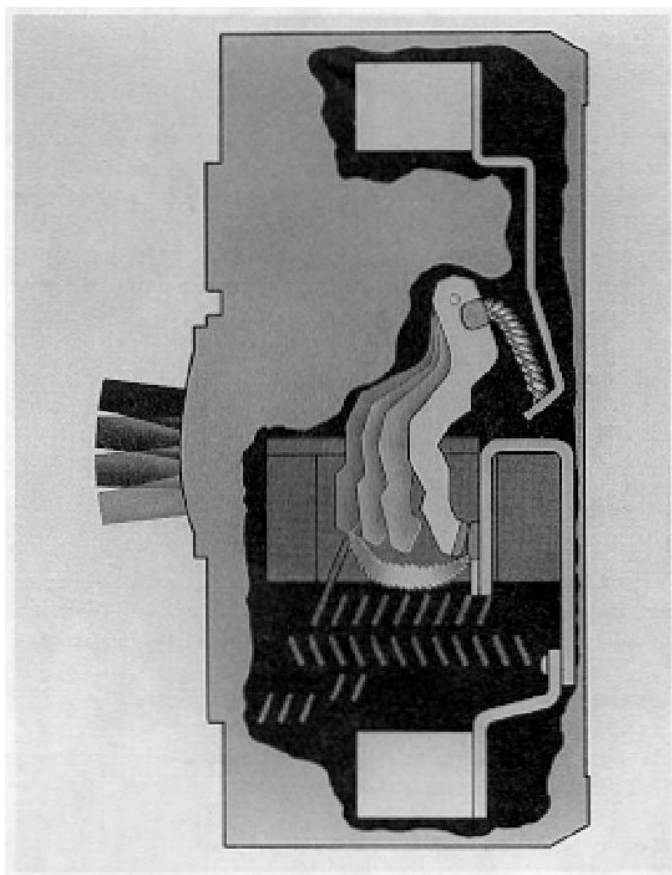
6.4.1 Description

Current-limiting circuit breakers are available from 15 A to 1200 A, rated up to 600 V, and have interrupting ratings up to 200 000 rms symmetrical A.

Current-limiting circuit breakers are conventional thermal-magnetic or electronic-trip circuit breakers, designed so that high-speed contact separation is achieved under high-level fault conditions. This high-speed contact separation effectively limits potentially high-level fault currents and is achieved by closely spaced parallel contact arms carrying current in opposite directions. One form of a current-limiting circuit breaker with high-speed contacts is illustrated in Figure 19. Current-limiting circuit breakers are generally labeled as such, and when labeled, current limiting must meet specific requirements set forth in UL 489. However, circuit breakers not labeled as current limiting may exhibit current-limiting performance under specific fault conditions, and it should not be assumed that because a circuit breaker is not labeled current-limiting, it does not exhibit some degree of current limitation under some fault conditions.

Current-limiting circuit breakers can be reset and service can be restored in the same manner as conventional circuit breakers even after clearing maximum-level fault currents. Of course, whenever a fault has occurred, it is important to remove the fault and its cause before reenergizing. If indications are that the

fault was a significant short-circuit, the circuit breaker should be examined before reenergizing. If there are cracks in the circuit breaker housing, if operation is difficult, or if there is severe discoloration, the circuit breaker should be replaced before reenergizing. NEMA AB 4 [B15] contains more detailed information on testing and inspecting circuit breakers that have been in service.



Source: Schneider Electric

Figure 19—Current-limiting circuit breaker

6.4.2 Applications

Current-limiting circuit breakers not only provide high interrupting ratings, they also limit let-through current and energy to load-side devices and conductors.

The current-limiting action is sufficient to reduce peak current, I_p , and I^2t let-through to values that lesser rated downstream circuit breakers can interrupt. A common application of this is using the current-limiting circuit breaker as either an integral or remote main breaker for lighting panelboards on systems with high available fault currents. This is called a series rating. It is important to note that manufacturers must test to demonstrate that the downstream device is protected in order to achieve a UL recognized series rating. There is currently no accurate method of calculating this protection.

6.4.3 Series ratings

UL recognized series ratings are available using upstream circuit breakers or fuses with current-limiting capability in series with lower rated downstream breakers. These recognized combinations have been tested to verify that the current-limiting circuit breaker will protect the downstream device under the test

conditions. Individual manufacturers of UL recognized series-connected ratings are published and may be found in the UL Recognized Component Directory. It is important to note that series ratings are not limited to current-limiting circuit breakers. Refer to Clause 4 for additional information.

It should be noted that selective coordination may not be provided above any current level at which the circuit breaker trip characteristic curves overlap. If a series rating and selective coordination is required, application information from the manufacturer should be consulted.

6.5 Molded-case switches

Molded-case switches are circuit breakers with the thermal overcurrent protection removed. The instantaneous short-circuit protection may or may not also be removed. When high-level instantaneous protection is provided, that fact will be indicated on the switch markings. When molded-case switches include instantaneous trip, they may trip and hence have an effect on system selectivity.

Standard molded-case switches have no thermal- or instantaneous-tripping elements. The term *non-automatic* has been used with these switches in the past.

6.5.1 Molded-case switches with instantaneous protection

Molded-case switches with instantaneous-trip elements do not provide overcurrent protection. However, they do include a preset nonadjustable instantaneous-trip element that serves to protect the switch against the damaging effects of high-level fault currents. For most applications, the standard (non-automatic) and automatic switches can be used interchangeably.

6.5.2 Ratings

Molded-case switches have a maximum continuous current rating that, if exceeded for long periods of time, may cause damage to the switch due to overheating. Neither standard nor automatic molded-case switches have interrupting ratings, as they are intended only to be a disconnecting switch, not a protective device. Molded-case switches must be protected by an overcurrent protective device of an equivalent or lower current rating. Even when protected by an overcurrent protective device, molded-case switches should not be applied on systems capable of delivering fault current in excess of their withstand rating. Molded-case switches may carry a withstand rating from 5000 A to 200 000 A and are labeled for use in series with a specific overcurrent protective device or devices. The short-circuit rating test is conducted with the switch in series with the overcurrent device or devices specified.

6.5.3 Applications

Molded-case switches provide a simple and compact disconnecting means. Additionally, they meet the requirements of Section 430.109 of the NEC, which lists the specific devices that are permitted for use as a disconnecting means.

Molded-case switches are capable of making and breaking load currents up to six times their marked rating. As a result, these switches can be applied where horsepower ratings are required.

6.6 Fused circuit breakers

Fused circuit breakers are available in both molded-case and power circuit breaker constructions. They provide high interrupting capability through the use of specially designed current-limiting fuses, termed limiters in this application to distinguish them from commercially available Class R, J, or L fuses. Such fuses are assembled into the housing of the circuit breaker or, in the case of high-ampere power circuit breaker frames, in a separate fuse truck. The limiters in these devices are designed to open, and need replacement, only after a high-level fault. The circuit breaker portion is interlocked so that when any limiter opens, the circuit breaker will automatically trip, opening all poles and eliminating the possibility of single phasing caused by the opening of one of the limiters. Additionally, many circuit breakers are equipped with a mechanical interlock that prohibits the circuit breaker from closing with a missing or open limiter.

In the MCCB construction, the limiters are generally located within an added housing and are separated from the sealed trip unit of the circuit breaker for easy access. In LVPCB construction, the limiters are mounted on the rear of the circuit breaker frame or in a separately mounted fuse truck. Both mounting methods provide easy access to the limiters.

6.6.1 Applying fused circuit breakers

For ideal coordination within the fused circuit breaker, fuses should be selected so that overcurrents and low-magnitude faults are cleared by thermal or long-time/short-time tripping action; intermediate-level short-circuits are cleared by short-time delay, magnetic, or instantaneous tripping action; high-level short-circuits are cleared by the current-limiting fuse and instantaneous tripping action. This selection is usually made by the manufacturer, although optional fuse selections are sometimes available that may affect this coordination.

The short-time delay characteristic is beneficial if coordination in the intermediate current range is desired. There may be a lack of coordination with the load-side protective devices when currents are in the current-limiting range of the fuse.

When applied on high short-circuit current capacity systems, the effects of the let-through characteristics of the fused circuit breakers on downstream equipment must be considered. The presence of the current-limiting fuse as part of the fused circuit breaker does not necessarily imply that the downstream equipment can adequately withstand the current let-through by the upstream fused circuit breaker. It is important to note that manufacturers of the circuit breaker and protected element combination must test per applicable standards to ensure that the down-stream device or devices is/are protected. There is no accurate method of calculating this protection via data commonly available to the user.

Fused circuit breakers may be used where very high fault currents are available. In addition, some fused MCCBs provide series short-circuit ratings with other MCCBs. These series ratings are higher than the load-side circuit breaker rating.

It should be noted that fused circuit breakers do not have any current-limiting effect until the current associated with the fault exceeds the threshold current of the limiter. Using fused breakers to protect standard breakers downstream is sound design, provided the manufacturer's coordination data are applied carefully. It needs to be understood that reduced size limiters may be necessary, but the use of these limiters could result in less than ideal coordination within the fused circuit breaker. This may cause frequent blowing of the limiters. In no case should combinations of trip devices and fuses that are not approved by the manufacturer be installed. Where fuses of different manufacture are being considered for the same system, the characteristics and peak let-through current of a given fuse rating may vary substantially between manufacturers.

It is important to note that electrical distributors who stock ordinary current-limiting fuses rarely stock these limiters. To distinguish these fuses from more common current limiting fuses, they are most typically

termed limiters or high-fault protectors by standards such as UL 489 and by many distributors. It is wise to consider keeping at least one set of spare limiters of each size used.

6.7 Circuit breaker and ground-fault circuit interrupter

A ground-fault circuit interrupter (GFCI) “is a device whose function is to interrupt the electric circuit to a load when a fault current to ground exceeds some predetermined value that is less than that required to operate the overcurrent protective device of the supply circuit,” according to UL 943-2006. The Class A GFCI opens the circuit when the current to ground is 6 mA or more. A common form of GFCI protection is one in which an MCCB is packaged together with the GFCI in a single unit, which combines the functions of overcurrent protection and GFCI protection. The circuit breaker function is the same as for any MCCB.

The purpose of a GFCI is protection of personnel from the potentially deadly effects of current passing through the human body. The 6 mA value is below the current level at which a person would be unable to let go of a conducting part. It is also below the value at which ventricular fibrillation is likely for adults or children (see Roberts [B21]).

Circuit breaker GFCIs are typically rated 120 V ac, single-pole and 120/240, 208Y/120, or 240 V ac, two-pole or three-pole with current ratings from 15 A to 60 A. Under the NEC, GFCIs are required in many locations in which, because of the presence of water or other conditions, electrocutions have resulted. Residential and commercial locations include bathrooms, kitchens, rooftops, spray washers, repair garages, swimming pools and other water recreation facilities, and similar locations.

6.8 Circuit breaker and arc fault circuit interrupter

The arc fault circuit interrupter (AFCI) is packaged together with MCCBs to provide protection against effects of arcing occurrences that could start fires. As with the GFCI, the unit has the full function of a circuit breaker and has the function of the AFCI.

The AFCI recognizes characteristics of current or voltage waves unique to arcing and causes the MCCB to trip when it recognizes an arc within a predetermined range of current. It must distinguish between potentially hazardous conditions and wave shapes of normal power that may look similar to that of a hazardous arc. Motors with brushes and some equipment with bimetallic temperature sensors, such as flat irons, have arcs that are normal power. Light dimmers, banks of computers, and equipment with filters sometimes have wave shapes that could look like an arc but are normal power.

Branch/feeder AFCIs detect arc faults line-to-neutral or line-to-ground in a circuit capable of delivering 75 A or more. Arcing current will be less than the available current. Commercially available branch/feeder AFCIs may also detect line-to-ground arcs of approximately 50 mA or more. The 75 A value is the lowest fault current level found in a survey of receptacle locations in residences within the United States. The primary purpose of the branch/feeder AFCI is protection of fixed wiring. The branch/feeder AFCI also protects against line-to-neutral or line-to-ground arcing in the branch circuit extension wiring. It addresses the category of fires caused by lower level short-circuits that would not open an overcurrent protective device fast enough to avoid fire.

Combination AFCIs detect arc faults line-to-neutral, line-to-ground, or in series with it in a circuit capable of delivering 5 A or more. It is intended to detect arcing current in fixed wiring and extension wiring that are likely to cause fire. The term combination means that this device combines protection needed for fixed wiring with that needed for extension wiring connected to receptacle outlets.

Although the primary application for AFCIs under the NEC is residential, they are also required in some commercial units used as dwellings. They also find application in commercial and industrial applications in which detection of arcing current is needed, although not required for these applications.

AFCIs are rated 15 A and 20 A and are available in one-pole units rated 120 V ac and in two-pole units rated 120/240 V ac. The product standard is UL 1699.

6.9 Supplementary protectors

A supplementary protector resembles a circuit breaker and shares many characteristics; however, it does not meet the requirements of UL 489 and is not usable as branch circuit protection. These devices are identified in the NEC and by UL as supplementary protectors and are covered by UL 1077, which defines a supplementary protector as follows:

A manually resettable device designed to open the circuit automatically on a predetermined value of time versus current or voltage within an appliance or other electrical equipment. It may also be provided with manual means for opening and closing the circuit.

When comparing this definition with the NEC definition of a circuit breaker, obvious similarities are apparent, but there are also important differences. Both devices may open automatically on a predetermined value of current, but beyond that the devices may be different. Some potential key differences are as follows:

- The definition states that a supplementary protector may be provided with manual means for opening and closing the circuit, manual operability is not required. A circuit breaker is defined as a device designed to open and close the circuit by manual means.
- Supplementary protectors are intended to be installed within an appliance or other end-use electrical equipment, which means these devices may not be used in distribution equipment such as a panelboard or switchboard where branch-circuit overcurrent protective devices are required.

Supplementary protectors are not intended as a substitute for branch-circuit overcurrent devices. This is clearly noted in Section 240.10 of the NEC. They are intended as supplementary, or additional, protection to the branch-circuit overcurrent device that must be present.

Unlike general-purpose branch-circuit protectors, which are UL listed, supplementary protectors are recognized components and are intended for use in equipment. They are typically intended to provide more specialized protection for a specific purpose, or even for a particular type of equipment. Some have horsepower ratings for use with motors, and some do not have horsepower ratings. Supplementary protectors have ratings and functionality depending on their intended use. Some have manual switching means, and some do not. Some trip on current levels, and some trip on voltage levels. There are many differences in the UL standards; a few important specific instances are as follows:

Overload protection: UL 489-2013 requires all circuit breakers to be tested at six times the ampere rating, but UL 1077-2005 only requires overload testing at 1.5 times rating. However, if the supplementary protector carries a horsepower rating, it is also tested at six times the ampere rating.

Short-circuit ratings: UL 489-2013 requires a minimum short-circuit interrupting rating of 5000 A for circuit breakers rated 250 V and less, and 10 000 A for circuit breakers rated more than 250 V. UL 1077-2005 devices do not have short-circuit ratings, but the standard does require a limited short-circuit test at a maximum current of 5000 A. The actual test value varies from 200 A to 5000 A depending on the rating. The tests and the acceptable results at the conclusion of the test are also different. UL 489-2013 requires the circuit breaker to interrupt the circuit twice. After these tests, the circuit breaker must still be functional and pass a dielectric test. UL 1077-2005 requires the supplementary protectors to be subjected to three operations. However, the device is allowed to be wired in series with a branch-circuit overcurrent protector such as a fuse or circuit breaker. The branch-circuit overcurrent protection is allowed to open during the

test. It is acceptable for the supplementary protector to become inoperable during the tests, but it cannot become a hazard.

Spacings: UL 1077-2005 spacing requirements for supplementary protectors depend on the application such as general industrial use, household appliances, household kitchen appliances, or commercial appliances. For example, a 600 V UL 489-2013 circuit breaker requires a spacing of 25.4 mm (1 in) through air and 50.8 mm (2 in) over surface, whereas a UL 1077-2005 supplementary protector for 600 V general industrial use requires a spacing of only 19.1 mm (3/8 in) through air and 12.7 mm (1/2 in) over surface.

Annex A

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

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¹⁰ The NESC is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

¹¹ CSA publications are available from the Canadian Standards Association, 5060 Spectrum Way, Suite 100, Mississauga, Ontario, Canada, L4W 5N6 (<http://www.csa.ca/>).

¹² IEC publications are available from the Sales Department of the International Electrotechnical Commission, 3 rue de Varembe, PO Box 131, CH-1211, Geneva 20, Switzerland (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org>).

¹³ IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

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